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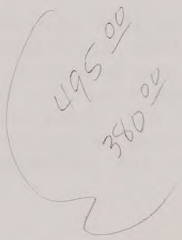

THERMAL TRANSFER DEVICES

INCLUDES:

Model 440 Selby Micropotentiometers
Model 1394A Thermal Voltage Converters
Model 1395A Terminated Thermal Voltage Converters
Model 1396A 50 Ohm Thermal Voltage Converters
Model 1397A Precision Thermal Voltage Converters

Ballantine Laboratories, Inc. P.O. Box 97 Boonton, New Jersey 07005 U.S.A.
Telephone: 201-335-0900 TWX: 710-987-8380

90-10013-5E

DECEMBER 1987

WARRANTY

This Ballantine Laboratories, Inc. product is warranted against defects in materials and workmanship for a period of one year from the date of shipment, except for batteries, electron tubes, vacuum thermal elements, and certain other components, if any, listed in this manual. Ballantine Laboratories, Inc. will, at its option, repair or replace products which prove to be defective during the warranty period provided they are returned to Ballantine Laboratories, Inc. prepaid, and provided the proper preventive maintenance and calibration procedures as listed in this manual have been followed. Repairs necessitated by misuse of the product are not covered by this warranty. NO OTHER WARRANTIES ARE EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. BALLANTINE LABORATORIES, INC. IS NOT LIABLE FOR CONSEQUENTIAL DAMAGES.

CERTIFICATION

Ballantine Laboratories, Inc. certifies that this equipment meets all applicable Ballantine specifications at time of shipment from the factory as determined by thorough testing and inspection. Ballantine further certifies that its measurements are traceable to the United States National Bureau of Standards. All instruments used in calibrating Ballantine products are standardized by systematic reference to NBS-traceable standards as described in the validation procedures shown below.

REFERENCE STANDARDS

DC	10mV-750V	0.002-0.003%
20Hz-50kHz	0.5V-500V	0.004%
20Hz-10MHz	0.5V-100V	0.05%
DC-30MHz	0.5V-100V	0.35%
DC-700MHz	10uV-0.5V	1%-NBS
10MHz-1000MHz	1V-300V	1%-NBS

WORKING STANDARDS

THERMAL VOLTAGE CONVERTERS, BALLANTINE 1397A
TRANSFER STANDARD, BALLANTINE 1605A
MICROPOTENTIOMETERS, BALLANTINE 440
RATIO TRANSFORMERS, GERTSCH

Ballantine's Quality Assurance program satisfied the requirements of MIL-I-45208

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SECTION 1.

440 Series

Selby Micropotentiometers

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440 Series
Selby Micropotentiometers

1. SPECIFICATIONS

Radial Resistors

Available in nominal values from .010 to 22 ohms with ± 25% tolerance. Each resistor is supplied soldered in a Type N female coaxial connector.

Housings

Normally supplied with either a 5, 10 or 15 mA UHF-type thermocouple. Higher thermocouple ratings available on request. Heater to thermocouple voltage must not exceed ± 50 V dc or peak ac. Heater current limited to 150% of rating.

Voltage Range

17 microvolts to 0.4 volt dependent on combination of radial resistor and thermocouple selected. Each combination will have a nominal output voltage equal to the product of resistance and rated thermocouple current, and can be varied from 1/3 to 1-1/3 of this nominal output.

Outputs greater than 0.4 volt can be obtained by using higher thermocouple ratings. For example, a 50 mA thermocouple with a 22-ohm resistor will produce outputs from 0.37 to 1.4 volts.

Frequency

DC to 900 MHz.

DC Reversal Error

The dc reversal error of the standard thermoelement is nominally ± 0.25%. Thermoelements with a dc reversal error of ± 0.005% (5 mA only) can be supplied on special request. Specify Option 08. Never exceed 5 mA heater current to maintain dc reversal error specification.

Accuracy

As of April 1982, the accuracies quoted on calibration certificates from the NBS Calibration Center, Boulder, Colorado, are 2% at 5 MHz, 3% at 100 MHz to 400 MHz, and 5% at 500 MHz to 900 MHz. Users of Micropotentiometers should check with NBS from time to time regarding any change in these figures.

Calibration and Certification

Model 440 Micropotentiometers may be calibrated and certified by the National Bureau of Standards Calibration Center, Boulder, Colorado, at frequencies up to 900 MHz. Because of the heavy work load at NBS, Ballantine has agreed to provide calibration for each Radial Resistor at the following frequencies: 5 MHz, 100 MHz, 300 MHz, 400 MHz. and 500 MHz. This service is supplied at no extra charge with the purchase of each Micropotentiometer.

Ballantine calibration and certification accuracies will be based on the accuracies of *special standards supplied for this service by NBS.* It is expected that the additional uncertainty introduced by the Ballantine calibration will not exceed 1% up to 900 MHz.

Calibration from above 500 MHz to 900 MHz can be provided by Ballantine on special request. Consult latest instrument price list for cost information.

2. PURPOSE

The Ballantine Model 440 Micropotentiometer is designed to provide a precisely determined voltage at its output terminal when dc to 900 MHz current is fed into the input terminal. The input current flows through a UHF-type thermocouple to a radial resistor of known constant value. The voltage developed across the resistor becomes the standard which can be used to calibrate electronic voltmeters, oscilloscopes, signal generators and other devices.

The Model 440 is manufactured by Ballantine Laboratories based on designs by Mr. Myron C. Selby of the National Bureau of Standards, Boulder, Colorado.

3. DESCRIPTION

Figure 1 shows the complete Model 440 Micropotentiometer assembly. Figure 2 is an exploded view showing the housing with a Type N male coaxial input connector, a UHF-type insulated thermocouple for monitoring the input current, two feed-thru capacitors to provide leads to a dc microammeter, and a special radial resistor which is built into a Type N female coaxial output connector. Figure 3 is a schematic circuit diagram of the instrument.

Construction of the radial resistor is most important, and special techniques must be used to make one whose resistance remains nearly constant from dc to 900 MHz. If the current provided by an external signal generator is maintained constant, as indicated by a constant thermocouple output read on an external dc microammeter or dc digital voltmeter (10 mV full scale range), the voltage drop across the radial resistor can be used as a precision low-impedance source of voltage whose output remains constant from dc to 900 MHz.

The nominal output voltage of a Model 440 is given by the product of the heater current rating of the thermocouple and the resistance of the radial resistor. This voltage can be varied from one-third to one and one-third of full rated output by varying the thermocouple current over a four-to-one range. To provide additional voltage ranges, any radial resistor can be easily removed with the aid of a screwdriver, and plugged into any other housing carrying a thermocouple of a different rating. If, for example, we

Figure 1 — Ballantine Model 440 Selby Micropotentiometer

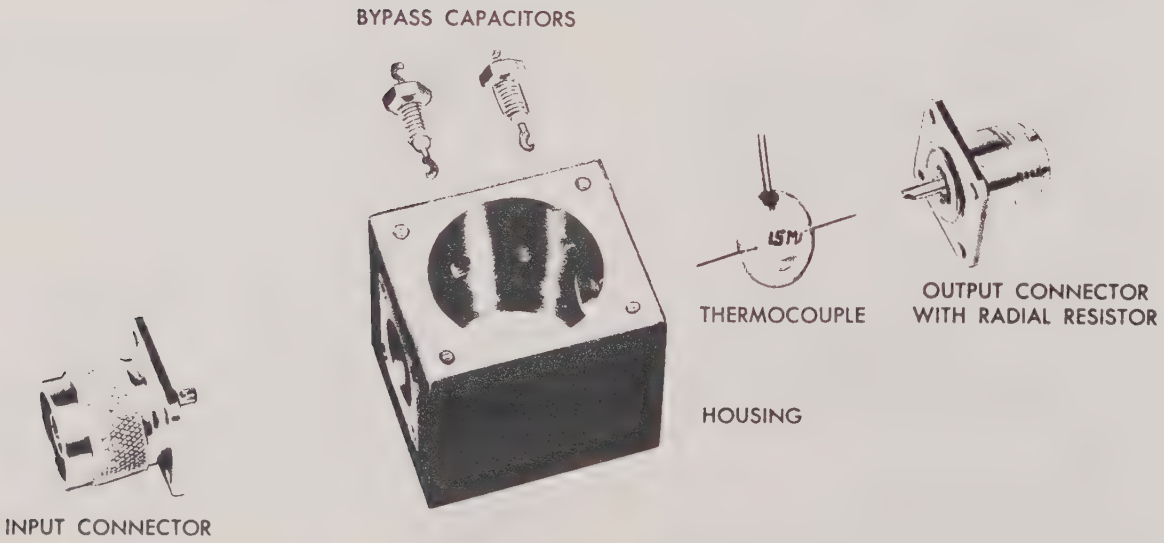

Figure 2 — Ballantine Model 440 Selby Micropotentiometer, Exploded View

INSTRUCTION MANUAL

THERMAL TRANSFER DEVICES

INCLUDES:

Model 440 Selby Micropotentiometers
Model 1394A Thermal Voltage Converters
Model 1395A Terminated Thermal Voltage Converters
Model 1396A 50 Ohm Thermal Voltage Converters
Model 1397A Precision Thermal Voltage Converters

Ballantine Laboratories, Inc. P.O. Box 97 Boonton, New Jersey 07005 U.S.A.
Telephone: 201-335-0900 TWX: 710-987-8380

90-10013-5E DECEMBER 1987

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20Hz-10MHz	0.5V-100V	0.05%
DC-30MHz	0.5V-100V	0.35%
DC-700MHz	10uV-0.5V	1%-NBS
10MHz-1000MHz	1V-300V	1%-NBS

WORKING STANDARDS

THERMAL VOLTAGE CONVERTERS, BALLANTINE 1397A
TRANSFER STANDARD, BALLANTINE 1605A
MICROPOTENTIOMETERS, BALLANTINE 440
RATIO TRANSFORMERS, GERTSCH

Ballantine's Quality Assurance program satisfied the requirements of MIL-I-45208

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SECTION 1.

440 Series

Selby Micropotentiometers

440 Series
Selby Micropotentiometers

1. SPECIFICATIONS

Radial Resistors

Available in nominal values from .010 to 22 ohms with ± 25% tolerance. Each resistor is supplied soldered in a Type N female coaxial connector.

Housings

Normally supplied with either a 5, 10 or 15 mA UHF-type thermocouple. Higher thermocouple ratings available on request. Heater to thermocouple voltage must not exceed ± 50 V dc or peak ac. Heater current limited to 150% of rating.

Voltage Range

17 microvolts to 0.4 volt dependent on combination of radial resistor and thermocouple selected. Each combination will have a nominal output voltage equal to the product of resistance and rated thermocouple current, and can be varied from 1/3 to 1-1/3 of this nominal output.

Outputs greater than 0.4 volt can be obtained by using higher thermocouple ratings. For example, a 50 mA thermocouple with a 22-ohm resistor will produce outputs from 0.37 to 1.4 volts.

Frequency

DC to 900 MHz.

DC Reversal Error

The dc reversal error of the standard thermoelement is nominally ± 0.25%. Thermoelements with a dc reversal error of ± 0.005% (5 mA only) can be supplied on special request. Specify Option 08. Never exceed 5 mA heater current to maintain dc reversal error specification.

Accuracy

As of April 1982, the accuracies quoted on calibration certificates from the NBS Calibration Center, Boulder, Colorado, are 2% at 5 MHz, 3% at 100 MHz to 400 MHz, and 5% at 500 MHz to 900 MHz. Users of Micropotentiometers should check with NBS from time to time regarding any change in these figures.

Calibration and Certification

Model 440 Micropotentiometers may be calibrated and certified by the National Bureau of Standards Calibration Center, Boulder, Colorado, at frequencies up to 900 MHz. Because of the heavy work load at NBS, Ballantine has agreed to provide calibration for each Radial Resistor at the following frequencies: 5 MHz, 100 MHz, 300 MHz, 400 MHz. and 500 MHz. This service is supplied at no extra charge with the purchase of each Micropotentiometer.

Ballantine calibration and certification accuracies will be based on the accuracies of *special standards supplied for this service by NBS.* It is expected that the additional uncertainty introduced by the Ballantine calibration will not exceed 1% up to 900 MHz.

Calibration from above 500 MHz to 900 MHz can be provided by Ballantine on special request. Consult latest instrument price list for cost information.

2. PURPOSE

The Ballantine Model 440 Micropotentiometer is designed to provide a precisely determined voltage at its output terminal when dc to 900 MHz current is fed into the input terminal. The input current flows through a UHF-type thermocouple to a radial resistor of known constant value. The voltage developed across the resistor becomes the standard which can be used to calibrate electronic voltmeters, oscilloscopes, signal generators and other devices.

The Model 440 is manufactured by Ballantine Laboratories based on designs by Mr. Myron C. Selby of the National Bureau of Standards, Boulder, Colorado.

3. DESCRIPTION

Figure 1 shows the complete Model 440 Micropotentiometer assembly. Figure 2 is an exploded view showing the housing with a Type N male coaxial input connector, a UHF-type insulated thermocouple for monitoring the input current, two feed-thru capacitors to provide leads to a dc microammeter, and a special radial resistor which is built into a Type N female coaxial output connector. Figure 3 is a schematic circuit diagram of the instrument.

Construction of the radial resistor is most important, and special techniques must be used to make one whose resistance remains nearly constant from dc to 900 MHz. If the current provided by an external signal generator is maintained constant, as indicated by a constant thermocouple output read on an external dc microammeter or dc digital voltmeter (10 mV full scale range), the voltage drop across the radial resistor can be used as a precision low-impedance source of voltage whose output remains constant from dc to 900 MHz.

The nominal output voltage of a Model 440 is given by the product of the heater current rating of the thermocouple and the resistance of the radial resistor. This voltage can be varied from one-third to one and one-third of full rated output by varying the thermocouple current over a four-to-one range. To provide additional voltage ranges, any radial resistor can be easily removed with the aid of a screwdriver, and plugged into any other housing carrying a thermocouple of a different rating. If, for example, we

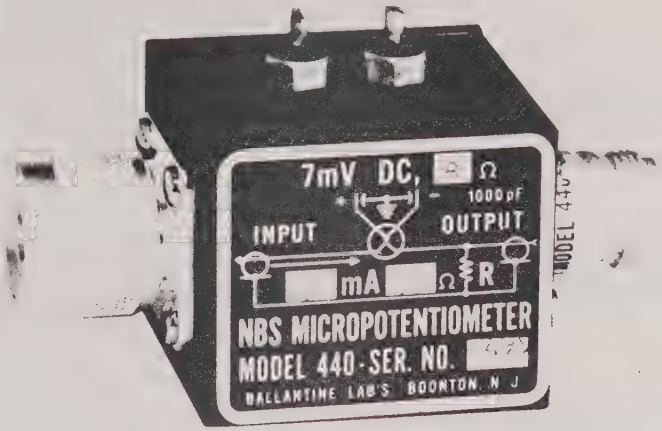


Figure 1 — Ballantine Model 440 Selby Micropotentiometer

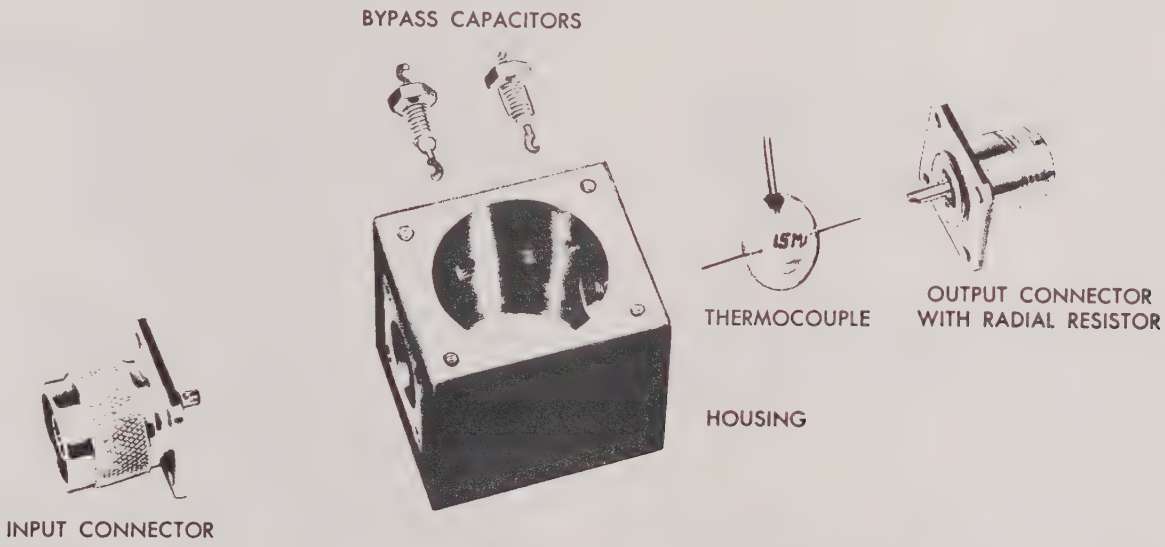


Figure 2 — Ballantine Model 440 Selby Micropotentiometer, Exploded View

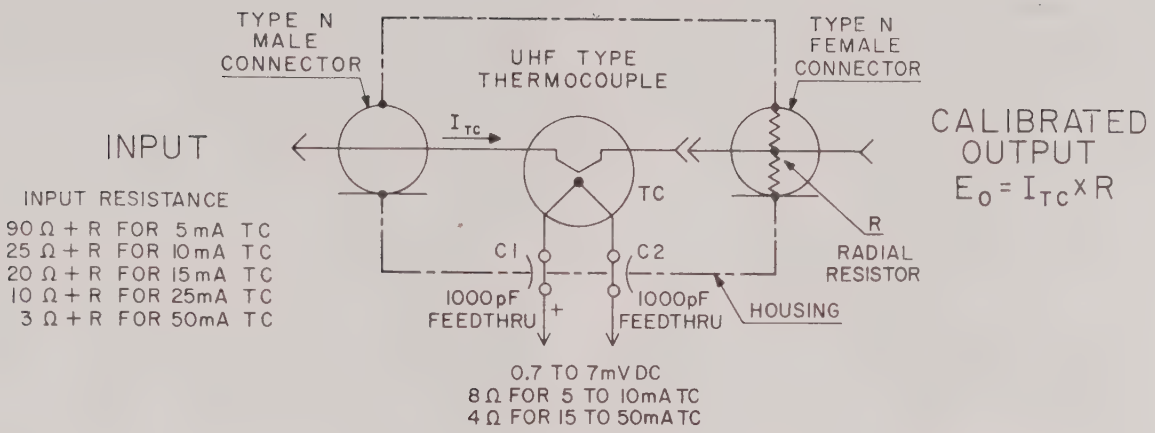


Figure 3 — Ballantine Model 440 Selby Micropotentiometer, Schematic Circuit Diagram

use a 0.02-ohm radial resistor and a 5-milliampere thermocouple it is possible to produce a standard voltage output of 100 microvolts for 5 milliamperes current, and 40 microvolts for 2 milliamperes current. Higher resistor values of 22 ohms, and thermocouples rated to 15 milliamperes may be used to produce voltages to approximately 0.44 volt. It is possible to use a 50 mA thermocouple with a 22-ohm radial resistor to obtain 1.4 volts provided the signal generator feeding the micropotentiometer is capable of supplying this amount of current.

Additional laboratory standard devices made by Ballantine are the Model 1396A Thermal Converter designed to measure voltages from 1 volt to 7 volts in the frequency range from dc to 1 GHz, and the Model 1394A Thermal Converter designed to measure voltages from 0.1 volt to 100 volts in the frequency range of 25 Hz to 30 MHz and 100 MHz. These are also based on NBS designs. The Model 1395A series are terminated to match balanced or single-ended transmission lines from 50 ohms to 600 ohms at voltages ranging from 0.08 volt to 8 volts rms at frequencies ranging from dc to 100 MHz. The Model 1600A Automatic Balancing AC/DC Transfer Standard provides automatic and manual wide-range measuring capabilities of voltages from 250 mV to 1 kV at frequencies ranging from dc to 30 MHz and up to 100 MHz with Option 88. Each model is supplied with calibration and correction data traceable to NBS.

4. OPERATION AND APPLICATIONS

The Model 440 Micropotentiometer is ready for use as received. It is necessary only to connect the input to a source capable of delivering the required current over the frequency range desired, and to attach a suitable dc microammeter to the thermocouple output. The Micropotentiometer is then ready to serve as a precision source of low-level, high-frequency voltage.

CAUTION

When making connections to the output connector avoid excessive strains on the center conductor to prevent damaging the radial resistor.

The rf output voltage of the Micropotentiometer, at any frequency, is given by the product of the thermocouple current, whose magnitude is indicated by the dc couple output, and the calibrated impedance of the radial resistor. Normally a Micropotentiometer will reproduce the same output voltages for long periods of time. However, the value of the radial resistor may change due to aging effects and the relationship of thermocouple heater current to dc couple output may change as the result of momentary overloads.

The Micropotentiometer output, however, can always be standardized at either dc or low-frequence ac where accurate milliammeters and voltmeters are readily available. Within its specified range the Micropotentiometer will then reproduce this voltage at high frequencies with an accuracy as shown on the Test Report. Standardization should be carried out at the ambient temperature at which the Micropotentiometer will be operated, or an additional error due to the temperature coefficient of the thermocouple will be introduced. In all cases, allow the thermocouple at least 10 minutes of operation at the desired current level to produce complete temperature stabilization.

CAUTION

Continuous current overloads of greater than 50%, or momentary overloads of more than 100%, can ruin or seriously alter the thermocouple characteristics.

Figure 4 shows a typical test setup using a Model 440 Micropotentiometer. One application of the Model 440 Micropotentiometer is in the calibration of sensitive high-frequency voltmeters. The Model 440 may be used to check the frequency response of voltmeters, relative to some reference frequency, or by calibrating the Micropotentiometer output against auxiliary standards at dc or low-frequency ac, it may be used as an absolute voltage standard. The Model 440 Micropotentiometer may also be used, in conjunction with an auxiliary transfer device, to calibrate the appropriate output levels of signal generators over a wide frequency range. Because the radial resistance is of a low value and securely soldered into a Type N coaxial connector, Micropotentiometers are useful devices whenever a stiff, well-shielded, high-frequency voltage source is required.

FOR USE AS A RELATIVE VOLTAGE STANDARD, dc to 900 MHz (to check frequency response of voltmeters, oscilloscopes, etc. For example, to calibrate the frequency response of a voltmeter in terms of an arbitrary reference level.)

1. Adjust the signal generator to a reference frequency.
2. Adjust the level of the signal generator to produce the desired Micropotentiometer output voltage into the voltmeter.

CAUTION

Do Not Exceed 150% of Rated Thermocouple Current.

3. Note the indication on the dc digital voltmeter.
4. Adjust the signal generator to a new desired frequency.
5. Adjust the level of the signal generator to produce the same voltage as in Step 3.
6. The Micropotentiometer output voltage into the voltmeter is now maintained at the arbitrary reference level selected in Step 2.
7. Repeat Steps 4-6 as required for each frequency.

FOR USE AS AN ABSOLUTE VOLTAGE STANDARD, dc to 900 MHz (to calibrate voltmeters, oscilloscopes, etc.)

1. Replace the signal generator in Figure 4 with a dc or low-frequency source.
2. Replace the voltmeter to be calibrated with a standard voltmeter (dc or ac, as selected in Step 1) having the correct voltage range and sufficient accuracy to measure the desired Micropotentiometer output voltage.
3. Adjust the level of the input until the standard voltmeter indicates the desired Micropotentiometer output voltage.
4. Note the indication on the dc digital voltmeter.
5. Replace the dc or low-frequency source with a signal generator covering the desired frequency range.
6. Replace the standard voltmeter with the voltmeter to be calibrated.
7. Adjust the level of the signal generator until the dc digital voltmeter indicates the same voltage as in Step 4.
8. The Micropotentiometer output voltage into the voltmeter is now maintained at the absolute level selected in Step 3.

Device To Be Calibrated (See Figure 4)

Certain precautions are necessary if the device to be calibrated is to respond as desired to the Model 440 output voltage. The input resistance of the device should not load

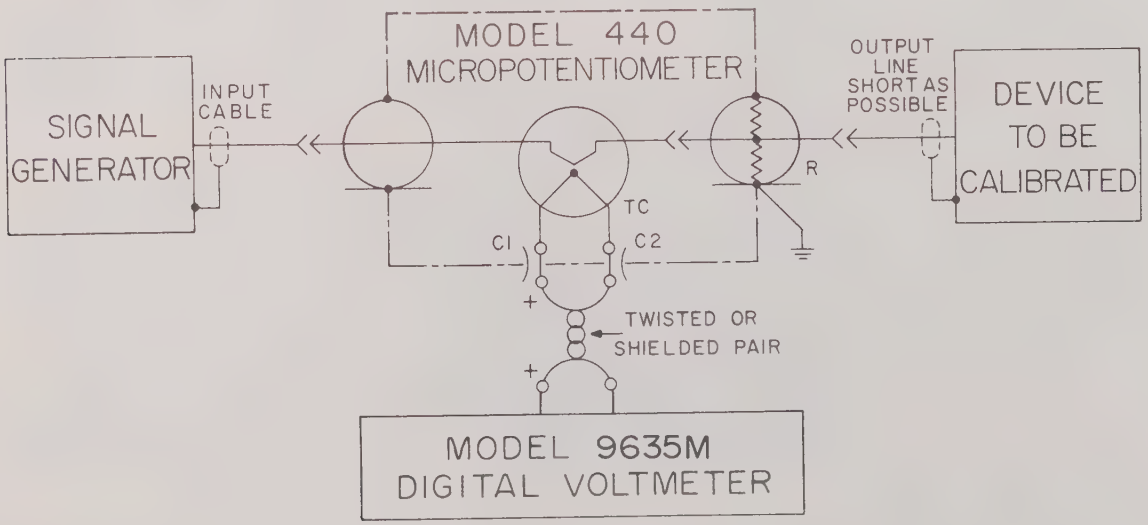


Figure 4 — Typical Test Setup

the Micropotentiometer, and the input capacitance should be small to minimize the transmission-line effect discussed below. The capacitance should be measured at the frequencies at which the measurements are to be made, rather than relying on a low-frequency value, because the two will often be considerably different.

In addition, consideration should be given to the effects of ground currents, even if an isolation transformer is being used. Any impedance existing between the input ground terminal of the device being calibrated, and the internal ground point to which the device responds (for example, the ground of the input tube of an amplifier) can serve, in the presence of ground current, to inject in series with the Micropotentiometer output an additional unknown and uncontrolled voltage. Correct grounding practices are absolutely necessary if a high-frequency voltage calibration is to be meaningful.

The purity of the waveform of the input signal is discussed below titled, "Signal Generator". If the device to be calibrated is true rms-responding, there should be no problem regarding the waveform of the source signal. If it is a peak or average-responding type of voltmeter, the waveform of the input signal is very important for precision measurements. Refer to paragraph "Signal Generator" for further information.

Output Cable (See Figure 4)

The output cable that connects the Model 440 to the device being calibrated should be as short as possible and in the form of a shielded coaxial cable to minimize ground current, pickup, and transmission-line effects.

If a length of coaxial cable is terminated in its characteristic impedance, the voltage along the cable will be constant and equal to the impressed voltage. If the cable is terminated in any impedance other than its characteristic impedance, the voltage along the cable will vary as a function of the terminating impedance, the characteristics and length of the line, and the frequency. Figure 5 shows the relationship of output voltage to impressed voltage for a section of transmission line terminated in a capacitance. For other terminations similar curves can be derived from standard transmission-line equations.

As an example of the transmission-line effect, assume a high-frequency voltmeter to be connected to a Micropotentiometer by means of a coaxial adapter. The total length from the flange of the Micropotentiometer to the output tip of the adapter is 2 inches. The voltmeter is to be calibrated at a frequency of 250 MHz where its input shunt resistance is 1000 ohms and its shunt capacitance is 6.4 pF. The shunt resistance can be neglected since it is large compared to the capacitive reactance. Using the formulas shown on Figure 5:

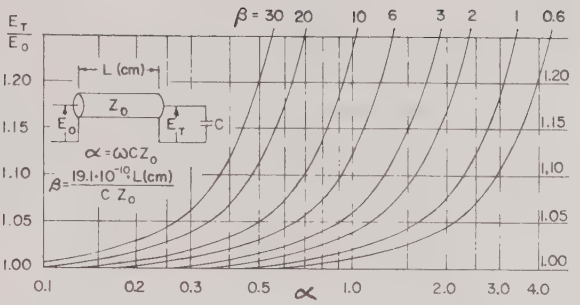


Figure 5 — This family of curves shows the relationship between the voltage at the flange of the output connector of the Model 440 and the voltage existing at distances from this point.

$$\alpha = \omega C Z_0 = 2\pi\ (250 \times 10^6)\ (6.4 \times 10^{-12})\ (50) = 0.5$$

$$\beta = \frac{19.1 \times 10^{-10} L\ (cm)}{C Z_0} = \frac{19.1 \times 10^{-10}\ (2 \times 2.54)}{(6.4 \times 10^{-12})\ (50)} = 30.4$$

Figure 5 then shows that the voltage appearing at the tip of the output UHF connector will be 20% higher than the calibrated output voltage of the Micropotentiometer. If the length of cable can be reduced to a length of approximately 0.4 inch, the error will be reduced to 3%. This example demonstrates the large errors that can occur at high frequencies due to the transmission-line effect, and illustrates the need for extremely short interconnections as the frequency increases.

Short interconnections are also necessary to reduce the effects of ground currents. *Circulating ground currents of various frequencies exist in any system of interconnected electronic equipment connected to a common power line.* If any appreciable impedance exists in the ground connection between the Micropotentiometer and the devices being calibrated, these currents will produce a voltage drop across the impedance which is injected in series with the Micropotentiometer output to the device. At the microvolt and millivolt level such extraneous signals can produce large errors. The ground impedance may be resistive, due to poor electrical connections, or excessive lead length, or inductive due to lead length, or failure to use coaxial cable and connectors.

The effects of ground currents can often be substantially reduced by using an isolation transformer. This transformer may be introduced in the power line of either the generator or the device being calibrated, where it must exhibit small coupling to high-frequency signals.

The output cable from the Model 440 must also be adequately shielded to prevent pickup of high-level signals in the low-level Micropotentiometer output.

DC Digital Voltmeter (See Figure 4)

A dc digital voltmeter is required to monitor the rf thermocouple heater current by responding to the dc output of the couple. The absolute accuracy of this indication is of secondary importance. It is important that the voltmeter be stable, easily read and reset to a reference value, and of correct sensitivity to indicate near full-scale voltage for rated thermocouple heater current.

All thermocouples used in the Model 440 have a nominal 7 millivolt open-circuit dc output for rated heater current. The 5 mA and the 10 mA type thermocouples have a dc output resistance of 8 ohms; the 15 mA unit has an output resistance of 4 ohms.

The dc output of the Model 440 is available at the terminals of two high-frequency bypass capacitors. The connection of the dc voltmeter should be made by either a shielded or a coaxial cable to prevent possible pick-up of low-frequency fields.

Input Cable (See Figure 4)

The input cable that connects the signal generator to the Model 440 may be of any convenient length. It should be a shielded cable to avoid leakage of the high-level generator output into the low-level Micropotentiometer output circuit. At the Micropotentiometer end, the cable should be terminated in a Type N female connector.

Signal Generator (See Figure 4)

The signal generator used to supply thermocouple heater current to the Model 440 must meet several requirements. Naturally it must be capable of delivering the desired current to the resistance provided by the thermocouple heater, and it must do so over the entire frequency band of interest. In addition, the generator must supply this current with minimum distortion.

The Model 440 is an rms-responding device because it uses a thermocouple to monitor the current that flows thru the radial resistor. If the device which is being calibrated at the output of the Micropotentiometer is also rms-responding, distortion in the waveform of the current supplied by the signal generator will have no effect on the accuracy of the calibration. However, if the device being calibrated is average or peak-responding, distortion in the waveform will cause an error in calibration. The amount of this error is proportional to the magnitude of the harmonics present and their phase relationship to the fundamental.

It may be difficult to measure adequately the distortion in the generator output at high frequencies. Oscilloscopes may be used for a visual indication, and an rf distortion meter may be valuable. The use of additional tuned circuits or coaxial low-pass filters between the generator and Micropotentiometer should also be considered as a means of reducing the error produced by the waveform if such distortion is suspected.

5. GENERAL DISCUSSION OF WAVEFORM vs. ACCURACY OF ELECTRONIC VOLTMETERS

Electronic voltmeters may be classified into three groups according to the way in which they respond to the input signal. In the first group are those instruments that measure the average value of the ac voltage. In most cases, the scale of the indicating meter of these instruments is calibrated to read in terms of the rms value of a sinewave. In the second group are the instruments that respond to the peak value of the ac voltage. All instruments having a diode rectifier at their input are included in this classification. Here again the scale calibration is usually in terms of the rms value of a sinewave. In the third group are the instruments, such as the Ballantine Model 323 Series and 3620A that respond to the actual rms value of the ac signal regardless of its waveform.

If a wave under measurement is a pure sinewave, the indicated rms values of all three groups of instruments will be the same. However, if the wave under measurement has harmonic or unwanted frequencies, the different groups of voltmeters will respond differently. In all cases the average-responding meters will give a much truer indication of the rms of the fundamental alone, or of the rms of the fundamental plus the harmonic, than the peak-responding-type meters. Of course the true rms voltmeter will be the most accurate of all when used to measure complex waveform voltages.

The amount of error introduced by a harmonic is a function of both its magnitude and its harmonic phase relationship. The following table compares the errors of two types of voltmeters in the rms indications of waves with various harmonics whose amplitude is 20% of the fundamental and whose phasing is such as to produce maximum error in each case.

The Model 440 Micropotentiometer is used to measure the true rms voltage regardless of the waveform of the input signal. If an average-responding or a peak-responding voltmeter is being calibrated it is essential that a pure sinusoidal signal be fed to the Micropotentiometer because this type of signal is the one on which the calibrations are based. If a true-rms voltmeter is being calibrated the waveform of the signal is of no importance.

Form of Wave	RMS Value of Fundamental	RMS Value of Fundamental plus Harmonic	Maximum Error in Indicated RMS Compared with RMS of Fundamental	
			Peak Responding Meter	Average Responding Meter
Pure Sine	1.	1.	0	0
Sine Plus 20% 2nd Harmonic	1.	1.02	20%	1.9%
Sine Plus 20% 3rd Harmonic	1.	1.02	20%	6.7%
Sine Plus 20% 4th Harmonic	1.	1.02	20%	1.7%
Sine Plus 20% 5th Harmonic	1.	1.02	20%	4.0%

APPENDIX A

MICROPOTENTIOMETER OUTPUT VOLTAGE COVERAGE WITH DIFFERENT RADIAL RESISTOR THERMOCOUPLE COMBINATIONS

The recommended range of voltage coverage for each Radial Resistor-Thermocouple combination is approximately four to one, that is, from approximately 35% above rated thermocouple current to 33% of rated thermocouple current. Thus a Radial Resistor of 0.10 ohm and a Thermocouple rated at 10 milliamperes may be operated between 330 and 1350 microvolts. A tabulation of the microvolt ranges for nominal values of Radial Resistors and for three Thermocouples is given in the table below.

Actual values of Radial Resistors will seldom have the exact nominal values shown in the table. If the Radial Resistor referred to above has 0.12 ohm instead of 0.10, the operating range with a 10 milliampere Thermocouple will be from 396 to 1620 microvolts.

The dc resistance of Radial Resistors will be ± 25% of the nominal resistances shown in the table below. Each Radial Resistor is identified by a serial number, and by its accurate dc resistance marked on a metal foil attached to the unit.

See page 3 regarding possible use of thermocouples having higher ratings than shown in the table.

RADIAL RESISTOR (Nominal value in ohms)	MINIMUM-MAXIMUM VOLTAGE				
	5 mA THERMO-COUPLE	10 mA THERMO-COUPLE	15 mA THERMO-COUPLE	25 mA THERMO-COUPLE	50 mA THERMO-COUPLE
0.010	17-67uV	33-135uV	50-200uV	83-338uV	170-670uV
0.015	25-100	50-200	75-300	124-506	250-1,000
0.022	37-145	75-290	110-440	181-743	370-1,450
0.033	55-220	110-440	165-660	272-1,114	550-2,200
0.047	80-310	160-620	240-940	388-1,586	800-3,100
0.068	115-450	230-900	340-1,350	561-2,295	1,150-4,500
0.10	.17-.67mV	.33-1.35mV	.50-2.00mV	.82-3.37mV	1.7-6.7mV
0.15	.25-1.0	.50-2.00	.75-3.00	1.23-5.06	2.5-10.0
0.22	.37-1.45	.75-2.90	1.10-4.40	1.81-7.42	3.7-14.5
0.33	.55-2.20	1.10-4.40	1.65-6.60	2.72-11.13	5.5-22.0
0.47	.80-3.10	1.60-6.20	2.40-9.40	3.87-15.86	8.0-31.0
0.68	1.15-4.50	2.30-9.00	3.40-13.50	5.61-22.95	11.5-45.0
1.0	1.7-6.7mV	3.3-13.5mV	5.0-20.0mV	8.25-33.75mV	17-67mV
1.5	2.5-10.0	5.0-20.0	7.5-30.0	12.37-50.62	25-100
2.2	3.7-14.5	7.5-29.0	11.0-44.0	18.15-74.25	37-145
3.3	5.5-22.0	11.0-44.0	16.5-66.0	27.22-111.37	55-220
4.7	8.0-31.0	16.0-62.0	24.0-94.0	38.77-158.62	80-310
6.8	11.5-45.0	23.0-90.0	34.0-135.0	56.10-229.5	115-450
10.	17.0-67.0mV	33.0-135.0mV	50.0-200.0mV	82.5-337.5mV	170-670mV
15.	25.0-100.0	50.0-200.0	75.0-300.0	123.75-506.25	250-1,000
22.	37.0-145.0	75.0-290.0	110.0-440.0	181.5-742.5	370-1,400

UHF THERMOCOUPLES

The thermocouples used in Model 440 Micropotentiometers are UHF units available from Ballantine.

Ballantine Part No.	Milli-amperes Rating	Approx. Resistance of Couple Circuit (ohms)	Approx. Resistance of Heater Circuit (ohms)
27-02951-1A	5	8	90
27-02952-1A	10	8	25
27-02953-1A	15	4	20
27-02954-1A	25	4	10
27-02955-1A	50	4	3
*27-10000-1A	5	8	90

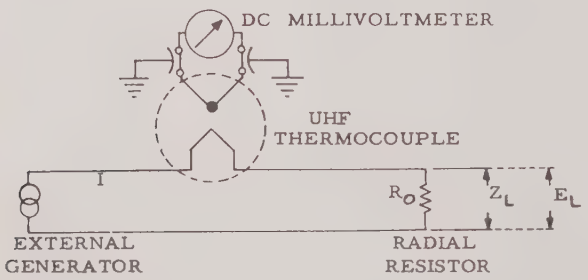
*Reversal error .005%.

ADDITIONAL NOTES CONCERNING THE CORRECTIONS FOR LOADING ERRORS WHEN USING MODEL 440 MICROPOTENTIOMETERS

In the past, some confusion has existed in the use of Micropotentiometers having radial resistors of 1 ohm or higher because of the increased importance of loading errors. This note will discuss the problem and describe how loading errors can be computed and their effect compensated.

Loading errors exist when an external load Z_L is small enough to shunt part of the thermocouple current I that normally flows through radial resistor R_O under open-circuit conditions. The effect is to change the voltage E_L across the load from that value determined by the produce of I and R_O. Loading errors must be considered not only when a Micropotentiometer is used as a *relative* voltage source, in determining the frequency response of some device, but also when an *absolute* voltage calibration is desired.

The circuit is as follows:



$$E_L = I \frac{R_O \quad Z_L}{R_O + Z_L}$$

Where E_L is the load voltage for a thermocouple current I

$$= E_O \frac{Z_L}{R_O + Z_L}$$

Where E_O is the open-circuit output voltage for a thermocouple current I

$$\text{or } E_O = E_L \left(1 + \frac{R_O}{Z_L}\right)$$

If $R_O << Z_L$, then E_L (the voltage delivered to the load) will equal E_O (the Micropotentiometer open-circuit output voltage) and there will be no loading error.

Notice that the loading effect need not be resistive. At higher frequencies it will also be necessary to measure the reactive part of Z_L to determine if loading errors are present.

In addition, at higher frequencies another effect enters into the loading error. If Z_L is connected to the Micropotentiometer output by a length of transmission line (which is always the case in practice), Z_L will be transformed to an equivalent Z_L' at the Micropotentiometer output. It is this value Z_L', determined by Z_L, the transmission line characteristics, and the frequency, which must be used in determining the loading error according to the above equation.

Other errors, both at low and high frequencies, are discussed in the Model 440 Instruction Book as well as in "Techniques and Errors in High-Frequency Voltage Calibration," Uiga and White, IRE Trans. on Inst., Vol. 1-9, No. 2, Sept. 1960. The latter paper is supplied with each instruction book for the Model 440.

REFERENCES OF VALUE

1. "Application of RF Micropotentiometers for Calibration of Signal Generators to 1000 Mc" by L. F. Behrent in National Bureau of Standards Technical Note No. 37 distributed by U.S. Dept. of Commerce, Office of Technical Services, Washington 25, D.C.
2. "Accurate Radio-Frequency Microvoltages" by Myron C. Selby in Communications and Electronics, AIEE 6: 158-164 (May, 1953).

MODEL 440-01 KIT

The Model 440-01 kit consists of five radial resistors and three thermocouple housings in a mahogany case, to cover the full range of voltages from 17 microvolts to 1.4 volts. Resistors supplied are in nominal values of 0.01, 0.1, 1, 10 and 22 ohms. Housings have thermocouples of 5, 15 and 50 mA. Ballantine calibration and certification to 500 MHz is included in the price of the kit. Additional calibration and certification can be supplied at points from above 500 MHz to 900 MHz. Consult latest Ballantine instrument price list for cost information.

APPENDIX B

USING THE 1610A CONTROL UNIT WITH MICROPOTENTIOMETERS

The 1610A Control Unit may be used to read out an NBS Micro Potentiometer such as the Ballantine 440 Series. The 1610A incorporates a Lindeck potentiometer consisting of the Null Meter and the offset millivolt bucking voltage.

To make micropot ac-dc transfer measurements with the 1610A use the following procedure:

a. Select the proper micropot terminating resistor and thermocouple to provide the output voltage required. See Section 1 for Ballantine 440 Micropotentiometers.

b. Connect the load to the resistor output of the Micropot and be sure the lead presents 50 ohms at the frequency of interest.

c. Ground the micropot to earth ground.

d. Connect the 1610A Control Unit to the micropot thermoelement using adapter cable Ballantine P/N 8910755-1. For micropots having a three pin MS connector thermo element output instead of solder lugs (such as the Ballantine 440A series) use adapter cable P/N 89-10756-1.

CAUTION

Be sure grounding of the 1610A and the micropot is secure so that the floating thermocouple output connections are never more than ± 50 volts peak off-ground. The operator and soldering iron must be grounded when connecting the adapter cable to the micropot.

NOTE

Observe polarity. Connect the positive thermocouple output (red dot) of the micropot to the gray wire (pin 5) of the adapter cable. Connect the negative thermocouple output to the red wire (pin 2).

e. If the dc setting is to be measured first so as to calibrate the micropot, connect a dc source to the input of the micropot and a dc voltmeter to the 50 ohm system in the output of the micropot.

f. Set the OFFSET mV switch on the 1610A Control Unit to 10 and the OFFSET mV ten-turn dial to zero.

g. Turn the 1610A Control Unit power to ON. Allow time for warm-up. Push the SET ZERO/NORMAL switch to SET ZERO and adjust the Null METER ZERO on the ± 100 uV FS range or on the most sensitive range to be used in the measurement.

h. Return the SET ZERO/NORMAL switch to NORMAL.

i. Apply dc input to the micropotentiometer. Slowly increase the dc input voltage until the voltmeter connected to the 50 ohm output system reads the voltage of interest (without correction for micropot dc to ac difference calibration).

CAUTION

Do not exceed the rated current of the micropot thermal element.

NOTE

Always select a measurement current and thermal element so that the micropot measurement is between the full rated current (i.e. 5 mA) and one-half the rated current (i.e. 2.5 mA). This assures accuracy by operating the thermal element in its rated square-law region.

j. Look up the micropot calibration correction data and add the correction factor of the dc to ac difference at the frequency of interest by changing the dc input voltage until the "corrected" (for ac/dc difference calibration of the micropot) dc output value is read by the dc voltmeter. Use this "corrected" dc input as read on the dc voltmeter for the ongoing test setup.

k. Allow the dc input and micropot output to fully stabilize.

l. Note that the NULL meter on the 1610A indicates an off-zero condition.

m. Increase the OFFSET mV dial setting until the NULL meter shows null.

NOTE

If a null cannot be attained, recheck the test setup and be certain of the polarity of the thermal element connections as indicated above.

n. Increase the sensitivity of the NULL meter and adjust the OFFSET mV dial until the desired null is achieved. Record the OFFSET mV dial setting.

o. Reverse the polarity of the dc input to the micropot.

p. Repeat steps i through m and record the OFFSET mV dial setting.

q. Take the average of the two OFFSET mV dial settings recorded in step m and o and set the OFFSET mV dial to this value.

$$\frac{\text{Dial setting (m)} - \text{Dial setting (o)}}{2}$$

The reversal error of the thermal element is presumed to be minimal (< 0.04%) so that the part of the square-law curve in use is linear. The OFFSET mV output is sufficiently stable to act as an analog memory until the ac output measurements of this micropot test are completed.

r. Disconnect the dc source and the dc voltmeter in the 50 ohm output system.

s. Set the output amplitude of the ac source at minimium and adjust its frequency to the frequency to be used in the measurement.

t. Connect the ac source to the input of the micropot and slowly increase the amplitude until the 1610A NULL meter indicates a null.

u. The ac output of the micropot has the same rms value as the fully "corrected" dc input (i.e. corrected for dc-to-ac difference calibration of the micropot and dc reversal error of its thermal element).

SECTION 2.

1394A Series

Thermal Voltage Converters

1394A Series
Thermal Voltage Converters

PART 1. GENERAL INFORMATION

1-1. PURPOSE

The Ballantine Thermal Converters (Figure 1-1) are wide frequency range rms voltage standards. They are designed to provide accurate voltage measurements, using AC/DC transfer techniques, and precise frequency influence tests.

Typical applications include:

a. Calibration of AC and RF voltmeters.

b. Frequency response measurements of signal generators, amplifiers and detectors.

1-2. SPECIFICATIONS

Voltage Ranges:

Model	Voltage Range
1394A-0.5	0.1 - 0.67 V (to 100 MHz)
1394A-1	0.2 - 1.3 V (to 100 MHz)
1394A-2	0.4 - 2.7 V (to 100 MHz)
1394A-3	0.6 - 3.9 V (to 100 MHz)
1394A-5	1.0 - 6.7 V (to 100 MHz)
1394A-10	2.0 - 13.5 V (to 100 MHz)
1394A-20	4.0 - 27.0 V (to 100 MHz)
1394A-50	10.0 - 65.0 V (to 30 MHz)
1394A-100	20.0 - 130.0 V (to 30 MHz)

1394H Series: Same as above, but supplied with ± 0.005% reversal error thermoelement. Never exceed 5 mA heater current to maintain dc reversal error specification.

Model 1934A - ( ) provides a 3 pin output connector. (Output grounding minimizes danger of exceeding voltage breakdown between heater and couple.) Model 1394A-MOD10 provides a 2 pin output connector.

NOTE

The 50 and 100 volt converters are specified thru 30 MHz although they are usable to 100 MHz. Other converters with nominal input voltage to 500 volts can be supplied on special order with reduced accuracy at higher frequencies.

Frequency Range: DC and 6 Hz to beyond 100 MHz.

Calibration Uncertainty

Frequency response checked with a standard converter traceable to NBS. Voltages measured at a point equivalent to the center of a General Radio Tee type GR 874 Series connected to the converter. Measurements reference 23°C ± 1°C.

Frequency Range	Comparison to Standard	Reference Standard Uncertainty
DC, 10 Hz to 20 Hz	within ±0.02%	±0.05%
DC, 20 Hz to 20 kHz	within ±0.01%	±0.01%
DC, 20 kHz to 50 kHz	within ±0.01%	±0.01%
DC, 50 kHz to 1 MHz	within ±0.01%	±0.05%
DC, 1 MHz to 10 MHz	within ±0.05%	±0.12%
DC, 10 MHz to 30 MHz	within ±0.20%	±0.25%
DC, 30 MHz to 50 MHz	within ±0.5%	±0.65%
DC, 60 MHz to 100 MHz	within ±1.0%	±1.02%

Input Resistance: 200 ±10 ohms per nominal volt

Input Capacitance: 5 pF nominal

Thermocouple: (23°C ± 1°C)

Nominal heater current — 5 mA

Max safe heater current — 7.5 mA

Couple Output — 7 mV ± 12% at nominal heater current

Couple Resistance — 8 ohms ± 10%

Max AC/DC Reversal Error — 0.05%

Temperature coefficient — 2000 ppm/°C

Couple output voltage to heater (ground) — Normally should not exceed ± 10 V, absolute max. ± 50 V peak

Operational Environment:

Temperature — +4°C to +40°C

Relative Humidity — 0 to 90%

Altitude — Sea level to 10,000 ft.

Mechanical Specifications:

Dimensions — 2" diam x 4 5/8" long exclusive of connectors (5.08 cm diam x 11.8 cm long)

Weight - 2.0 lbs. (907 gm)

Connectors	1394A	1394A-MOD10
Input	GR874PB	GR874PB
Output	3 pin Male MS3102A-10SL-3P	2 pin Male MS3102A-10SL-4P
(Optional) Mating Connector	3 pin Female MS3106A-10SL-3SC (31-10002-0)	2 pin Female MS3106A-10SL-4S (31-10348-0)

Figure 1-1. 1394 Series Thermal Voltage Converter

PART 2. CIRCUIT DESCRIPTION

Each Model 1394 Coaxial Thermal Converter consists of a stable, film type resistor in series with a high frequency thermocouple. The combination is mounted coaxially in a cylindrical tube, the diameter of which is designed to provide a nearly-constant transadmittance over a wide frequency range. Lower voltage probes have capactive compensation across the thermocouple; higher voltage probes have capacitive compensation from the body of the resistor to ground to provide as flat a frequency response as possible.

The basic schematic is shown in Figure 2-1.

To use a Model 1394 Thermal Converter it is necessary to monitor the DC couple output. The instrument used for this purpose need not be accurate; it must have resolution sufficient for the accuracy of voltage measurement being performed and short-time stability for the period of measurement.

For voltage measurements it is necessary to have a stable source of DC voltage capable of being set to the level of the AC voltage being measured. This source should be capable of delivering 5 mA into a 100 ohm to 4,000 ohm load with a 10 minute stability of 0.01% and with a precision of setability of 0.01% or better.

If reverse DC measurements are made, to eliminate the effect of reversal errors, the DC source must be operated ungrounded since one end of the thermocouple heater is grounded in the Model 1394.

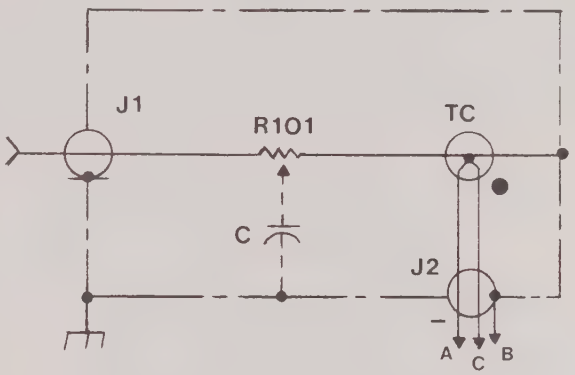


Figure 2-1. Schematic Diagram

PART 3. OPERATION

3-1. PRECAUTIONS

The thermocouple heater of the Model 1394 can withstand continuous overloads of 20% (to 6 mA) and momentary overload of 50% (to 7.5 mA). Overloads greater than these can result in a permanent change of thermocouple characteristics or burnout of the heater. Burnout occurs so rapidly that the rise in DC couple output cannot be detected. Therefore it is necessary to take every precaution to avoid overloading the thermocouple.

a. Be sure the voltage being measured is reduced to its lowest value before connecting or disconnecting the Model 1394 input.

b. Provide a method for monitoring or controlling the voltage being measured.

c. Do not change the frequency of the voltage being measured without first reducing the voltage to its lowest value.

d. Do not allow the open-circuit DC couple voltage to exceed 7 millivolts (equivalent to 5 mA of heater current).

e. Ground all test equipment and never exceed the breakdown voltage rating between heater and couple.

3-2. VOLTAGE MEASUREMENTS

Voltage measurements are made with the Model 1394 Coaxial Thermal Converters by using the principle of AC to DC transfer. An unknown AC voltage applied to the input of a Model 1394, chosen to have a voltage range appropriate for the measurement, will cause a rise in temperature of the thermocouple heater proportional to the RMS value of the AC voltage. This temperature rise will in turn produce a DC couple output proportional to the square of the AC voltage. If the Model 1394 is now transferred to a source of DC voltage and this source is adjusted until the DC couple output of the thermocouple is exactly the same value as it was when the AC voltage was applied, the resulting DC heater current is equal to the RMS AC heater current. Assuming a constant transadmittance of heater current to input voltage and no frequency errors in the thermocouple response, this DC input voltage is now exactly equal to the unknown AC voltage. Any measurement errors resulting from non-constant transadmittance or thermocouple frequency response are expressed as the AC/DC transfer difference. Such errors can be corrected to obtain the best measurement accuracy.

To measure the RMS value of an unknown AC voltage refer to the block diagram of Figure 3-1 and proceed as follows:

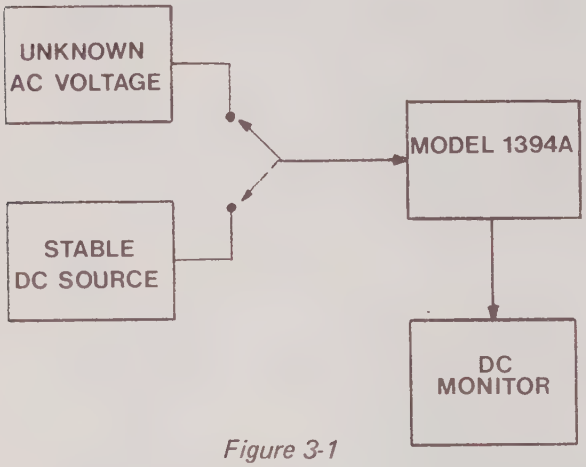


Figure 3-1

a. Select a Model 1394 whose voltage range includes the voltage to be measured. If the approximate value of the voltage is unknown, either obtain an approximate value from an auxiliary voltmeter or start the measurement process with the highest range Model 1394 and subsequently select lower range Model 1394's until the correct range is found.

b. Connect an appropriate DC monitoring instrument to the DC couple output of the Model 1394. This connection is made by a twin-contact shielded connector.

c. Reduce the level of the AC voltage to be measured to its lowest value.

d. Connect the unknown AC voltage to the coaxial input of the Model 1394.

e. Adjust the AC voltage to its desired level.

f. Note the indication of the DC monitor connected in step. b. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

g. Reduce the level of the AC voltage.

h. Disconnect the input of the Model 1394 from the AC source.

i. Reduce the level of an appropriate DC source to its lowest level.

j. Connect the DC source to the coaxial input of the Model 1394.

k. Adjust the level of the DC source until the DC monitor indicates the same reading as obtained in step f. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

l. Measure the value of the DC source. This value, corrected for any AC/DC transfer error, is the RMS value of the unknown AC voltage.

m. For greatest measurement accuracy, to eliminate the effects of DC reversal error in the thermocouple heater, steps i thru l should be repeated with the opposite polarity of DC. Use the average of the two DC voltages, corrected for AC/DC transfer errors, to determine the RMS AC voltage.

n. Reduce the level of the DC source to its lowest level.

o. Disconnect the input of the Model 1394 from the DC source. This completes the measurement procedure.

3-3. FREQUENCY RESPONSE MEASUREMENTS

Frequency response measurements can be made with the Model 1394 Coaxial Thermal Converters by utilizing the nearly-constant transadmittance of the Model 1394 over its frequency range. In this mode of operation the absolute level of voltage at the input of the Model 1394 is not determined by an AC to DC transfer. Instead a relative level of voltage is maintained constant at the input of the Model 1394 for all frequencies of interest. The Model 1394 can be used in this manner to determine the frequency response error of an AC voltmeter, as shown in the block diagram of Figure 3-2a. The frequency response of an amplifier can be measured as shown in Figure3-2b. Here the constant AC source could be obtained by using another Model 1394 to monitor and keep constant the input to the device under test.

3-4. Frequency Response Measurement of AC Voltmeters

A normal voltmeter calibration consists of two steps:

a. Measurement of voltmeter accuracy at midband (0.4 to 1 kHz)

b. Measurement of frequency response errors relative to midband.

The Model 1394 is very suitable for maintaining a constant AC voltage at the input of a voltmeter to determine its frequency response. Referring to Figure 3-2a proceed as follows:

a. Connect a stable AC source and the Model 1394 of proper voltage range for the measurement desired to the input of the voltmeter under test. Use short coaxial connections between the Model 1394 and voltmeter input to minimize transmission line errors.

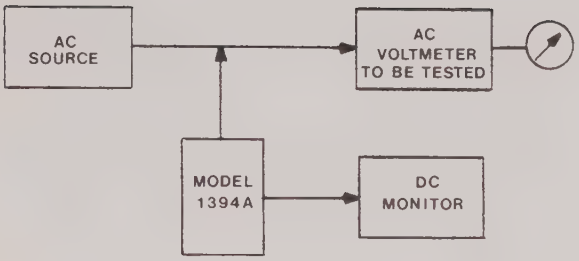


Figure 3-2a

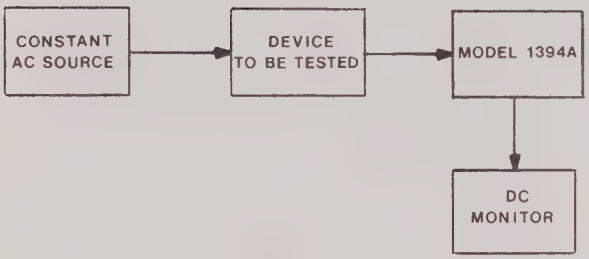


Figure 3-2b

b. Connect a suitable DC monitor to the DC couple output of the Model 1394.

c. Set the frequency of the AC source to a convenient midband frequency. This frequency should be chosen to be in a region where the voltmeter exhibits no frequency errors.

d. Adjust the level of the AC source to obtain a desired reference indication on the voltmeter under test.

e. Note the indication of the DC monitor connected in step b. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

f. Reduce the level of the AC source.

g. Set the frequency of the AC source to a new frequency.

h. Readjust the level of the AC source until the DC monitor indicates the same level as in step e.

i. Note the indication of the voltmeter under test. Any change in indication from the reference level of step d, adjusted for any transfer error in the Model 1394 between the two frequencies, represents the frequency response error of the voltmeter.

j. Repeat steps f thru i for all frequencies of interest.

3-5. Frequency Response Measurement of AC Amplifiers, etc.

Referring to Figure 3-2b, proceed as follows:

a. Connect the AC source to the device to be tested. Reduce its level as low as possible.

b. Connect a Model 1394 of proper voltage range to the output of the device. Keep the connection coaxial and as short as possible to avoid transmission line errors.

c. Connect a suitable DC monitor to the DC couple output of the Model 1394.

d. Set the frequency of the AC source to a convenient midband frequency. This frequency should be chosen to be in a region where the device exhibits no frequency errors.

e. Adjust the level of the AC source to the desired value. If this is being done by the use of another Model 1394, follow the steps of 3-4 outlined above.

f. Note the indication of the DC monitor connected in step c.

g. Reduce the level of the AC source.

h. Select a new frequency of the AC source.

i. Adjust the level of the AC source to the same value as in step e.

j. Note the indication of the DC monitor. The percentage change in indication from that obtained in step f is nearly twice the percentage change in frequency response of the device (because of the approximate square-law thermocouple characteristic).
If the most accurate measurement is required the Model 1394 should be transferred to an appropriate DC source and this source adjusted to the two values necessary to produce the same DC monitor indication as in steps f and j. The change in DC source voltage, corrected for any AC to DC transfer errors in the Model 1394, represents the frequency response error of the device being tested.

k. Repeat steps d thru j for all frequencies of interest.

3-6. MEASUREMENT ERRORS

3-7. Thermocouple Errors

Ideally, one end of the heater of the thermoelement should be grounded. If the average for the two directions of direct current is used as the reference, an ungrounded DC current is required. In any case the voltage difference between the heater and thermocouple should not exceed one or two volts because of the possibility of errors from the heating of the insulating bead by small currents through it.

Since thermoelements have a frequency response which extends to 100 MHz or more, they should be used in areas of reasonably low field strength. Interference from TV stations can be particularly troublesome with low-current thermoelements. A quick check of leadborne interference is easily made by shortcircuiting the input terminals, with the connections to the standard in place as in use, but with all power supplies off. There should be no change in indication of the detector in the output circuit of the thermoelement. If the standard has output terminals for a potentiometer or galvanometer, there should be no change in the output when a capacitor (at least 1000 pF) is connected across the output terminals after a balance has been obtained in a measurement. If RF pick-up is detected it may be necessary to provide additional shielding or to use the instrument in a shielded room.

3-8. Connection Errors

Connection errors should be evaluated and minimized when an AC/DC transfer standard is used to calibrate other instruments. These errors can often be detected by changing the length and position of the leads. Short coaxial leads should be used when possible. Voltages induced in loops formed by the connections to (or within) a low-range voltmeter or to a shunted thermoelement can be significant at high frequencies, particularly when high currents are being measured. When low currents are being measured the capacitance from the lead between the standard and the test instrument to ground or other parts of the circuit can cause errors. At any frequency, differences in the impedance of the two pairs of leads from a thermal voltage converter to (1) the DC standard and (2) the point at which the DC voltage is measured must be negligible compared with the resistance of the converter. NBS AC/DC difference tests are made at the AC input posts only.

PART 4. MAINTENANCE, CALIBRATION & REPAIR

The Model 1394 is constructed of the best commercial components which are then carefully inspected, assembled, tested and calibrated. Because each Model 1394 contains only passive components the service life should be very long if the instrument is not overloaded or misused. NBS suggests that a recalibration interval of not less than five years is indicated for this class of voltage standard.

4-1. MAINTENANCE

No routine maintenance is required for the Model 1394 except for occasionally checking that all hardware is secure and the external surfaces are free of dirt and dust.

4-2. CALIBRATION

Because of the accuracy class of the Model 1394, it can only be calibrated by similar basic voltage standards. The most accurate source for such calibrations is the National Bureau of Standards. Calibrations to 50 kHz are available at Washington, D.C. and higher frequency calibrations at Boulder, Colorado. Ballantine Laboratories also maintains a set of Model 1394 Converters specially calibrated by NBS to use as standards for the Model 1394.

One Model 1394 can be checked against another Model 1394 if the second converter has the same nominal voltage range or differs from the first converter by no more than one voltage range. The comparison is made by connecting the two converters together with a GR 874 Tee and feeding the junction of the tee with voltages of different frequencies. Using one Model 1394 as a standard the frequency response of the other Model 1394 is measured. Any difference in response from that expected from the AC/DC transfer difference, corrected for the transfer difference of the "standard" Model 1394, is an error in calibration.

If recalibration is indicated, it is recommended that the Model 1394 be returned either to Ballantine Laboratories or the National Bureau of Standards. If this is impractical the following procedure, with numerical example, should be followed:

a. Connect the "unknown" Model 1394 to be calibrated and a "standard" Model 1394 of the same or adjacent voltage range as shown in Figure 4-1. The source should be capable of delivering both DC and AC signals at the desired frequencies to the two Model 1394's. The two DC monitors need not be accurate but should exhibit short-time stability. The DC voltmeter should be capable of measuring the DC source voltage to an accuracy commensurate with the desired calibration accuracy.

b. Apply a DC voltage to both Model 1394's, measuring this voltage with the DC voltmeter and noting the indications of the two DC monitors. In the example shown:

DC source voltage	= 2.00 V
Unknown DC Monitor	= 6.70 mV
Standard DC Monitor	= 7.00 mV

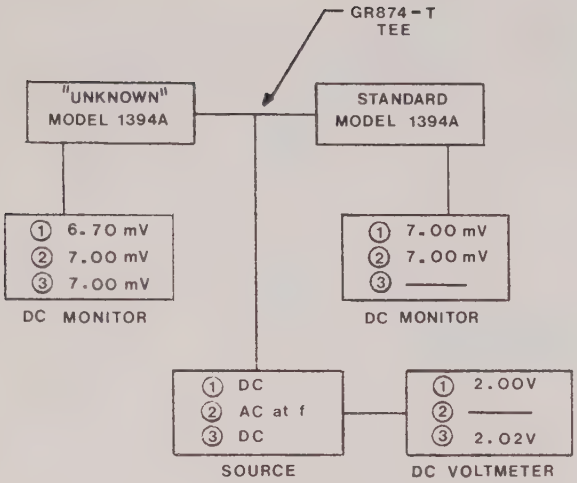


Figure 4-1

c. Apply an AC source of frequency f_1 to both Model 1394's, adjusting the level of the source to obtain the same indication on the "standard" DC monitor as in step (1) and noting the indication of the unknown DC monitor. In the example shown:

Standard DC Monitor = 7.00 mV
Unknown DC Monitor = 7.00 mV

d. Reapply the DC source, adjusting the source to obtain the unknown DC monitor indication of step c and measuring the DC source. In the example:

Unknown DC Monitor = 7.00 mV
DC source voltage = 2.02 V

e. If there is no AC/DC transfer difference at f_1 for the "standard" Model 1394, the above procedure assures that the AC input voltage to the unknown Model 1394 is the same as the DC source voltage measured in step b. If the DC source voltage measured in step d is not the same value, the percentage difference is the AC/DC transfer difference of the "unknown" Model 1394. In the example:

$$\text{AC/DC transfer difference at frequency } f_1 = \frac{2.02-2.00}{2.00} \times 100 = 1.0\%$$

f. If there is an AC/DC transfer difference at f_1 for the "standard" Model 1394, this difference must be subtracted from the AC/DC transfer difference determinded in step e. Assume in the example that the "standard" Model 1394 has a −0.2% AC/DC transfer difference at f. Then:

$$\text{Corrected AC/DC transfer difference at } f_1 = 1.0-(-0.2) = 1.2\%$$

4-3. THERMOCOUPLE REPLACEMENT

Field replacement of the thermocouple used in the Model 1394A is possible provided that the following steps are closely followed. Use only an exact replacement. A 5 mA UHF Thermocouple with a 0.05% reversal error P/N 27-07946-0A is available from Ballantine Laboratories, Inc.

a. Remove the circular Ballantine logo label located on the top of the 1394A.

b. Unsolder the thermocuple lead from the cover.

c. Remove the cover.

d. Unsolder the thermocouple leads from the side connector.

e. Remove the four mounting screws located at the input connector.

f. Remove the input connector from the barrel very carefully to avoid any damage to the assembly consisting of the series resistor, thermocouple and compensating capacitor.

g. Unsolder the remaining lead from the thermocouple.

h. Cut and shape the leads of the replacement thermocouple to conform exactly to the unit just removed.

i. Reassemble the 1394A by reversing the procedure listed above.

CAUTION

Use grounded soldering iron with 3 wire power cord to avoid exceeding heater to couple voltage rating.

i. If the replacement is done carefully it should not affect the AC/DC transfer difference. Follow the procedure of 4.2 to check the calibration.

NOTE

For calibration and repairs other than thermocouple replacement we recommend that the Model 1394 be returned to Ballantine Laboratories. Please include a letter describing the malfunction and/or the desired service. Pack the instrument with at least four inches of padding material all around and ship via REA, UPS, motor truck or freight to

Ballantine Laboratories, Inc.
90 Fanny Rd. (P.O. Box 97)
Boonton, New Jersey 07005 USA

Call Factory for Return Authorization

PART 5. REPLACEMENT PARTS

Model	Part No.	Symbol	Description
1394A-0.5	12-13111-0A	R1	10 ½W 1% RN60D
1394A-1	12-01511-0A	R1	110 2W 1% PME80
1394A-2	12-02688-0A	R1	310 2W 1% PME80
1394A-3	12-12829-0A	R1	511 2W 1% PME80
1394A-5	12-02689-0A	R1	900 2W 1% PME80
1394A-10	12-02690-0A	R1	1.9K 2W 1% PME80
1394A-20	12-02691-0A	R1	3.9k 2W 1% PME80
1394A-50	12-02992-0A	R1	10k 2W 1% PME80
1394A-100	12-01508-0A	R1	20k 2W 1% PME80
All Models	31-10109-0A	J1	Connector Type 874
All Models	31-10001-0A	J2	Connector MS3102A-10SL-3P
All Models	27-07946-1A	TC	5 mA, UHF Thermocouple (0.05% Reversal Error)
All Models	46-10000-0A		Ferrite Beads, 57-0180-7D
"H" Series (Optional)	27-10000-0A	TC	5 mA, UHF Thermocouple (0.005% Reversal Error)

OPTIONAL ACCESSORIES

Model	Part No.	Description
All Models	12257A (89-10284-5F)	Low noise connector and cable assembly
All Models	13940A	Storage Case for 4 converters
All Models	13941A	Accessory connector kit. Includes cable and various coaxial adapters
All Models	10130A	3-pin mating "MS3106-A-10SL-3S" output cable connector with clamp and bushing

SECTION 3.

1395A Series
Terminated
Thermal Voltage Converters

1395A Series
Thermal Voltage Converters

PART 1. GENERAL INFORMATION

1-1. PURPOSE

The Ballantine Thermal Converters (figure 1-1) convert complex ac input signals to dc voltages, accurately proportional to the rms value of the input. All models essentially have a flat response from 5 Hz to 10 MHz.

Typical applications of the thermal converters include:

a. Calibration of ac and rf voltmeters.

b. Frequency response measurements of signal generators, amplifiers and detectors.

c. Power measurements of complex waveforms in 50 ohm systems. Converter output voltage is proportional to true input power.

Table 1-1. Calibration Uncertainty

Frequency Response checked with a standard converter traceable to NBS. Voltages measured at a point equivalent to the center of a BNC Tee Type UG 274B/U connected to the converter.

Frequency Range	Comparison/ to Standard	Reference Standard Uncertainty
DC, 5 Hz to 20 Hz	within ± 0.05%	± 0.12%
DC, 20 Hz to 20 kHz	within ± 0.01%	± 0.02%
DC, 20 kHz to 50 kHz	within ± 0.01%	± 0.03%
DC, 50 kHz to 1 MHz	within ± 0.01%	± 0.06%
DC, 1 MHz to 10 MHz	within ± 0.05%	± 0.12%

1-2. SPECIFICATIONS

Voltage Ranges:

Model	Z	Voltage Range
1395A-0.4	50 Ω	0.08 - 0.54 (to 10 MHz)
1395A-1	50 Ω	0.2 - 1.3 (to 10 MHz)
1395A-3	50 Ω	0.6 - 3.9 (to 10 MHz)
1395A-6	50 Ω	1.2 - 8.1 (to 10 MHz)
1395A-1 MOD 75	75 Ω	0.2 - 1.3 (to 10 MHz)
1395A-1 MOD 93	93 Ω	0.2 - 1.3 (to 10 MHz)
1395A-1 MOD 135	135 Ω	0.2 - 1.3 (to 10 MHz)
1395A-1 MOD 150	150 Ω	0.2 - 1.3 (to 10 MHz)
1395A-1 MOD 600	600 Ω	0.6 - 3.9 (to 10 MHz)

1395H Series: Same as above, but supplied with ± 0.005% reversal error thermoelement. Never exceed 5 mA heater current to maintain dc reversal error specification.

RMS voltage is continuous maximum equivalent to dc heating value. Peak voltage at 30% maximum duty factor and represents absolute maximum value for recurrent or non recurrent input signals with on time < 1 ms.

Input Resistance: 50Ω ±0.15Ω dc and nominally constant beyond 10 MHz.

Calibrated Frequency Range: DC and 5 Hz to 10 MHz.

Usable Frequency Range: Dc and 5 Hz to greater than 100 MHz.

Thermocouple Characteristics (at 23°C ±1°C):

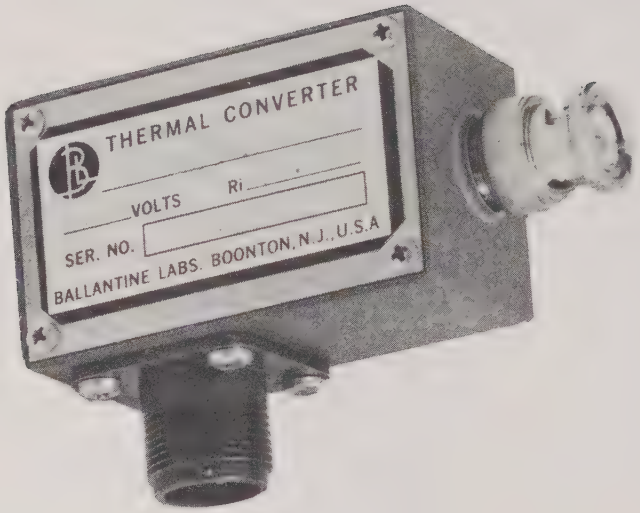
Nominal heater current	5 mA at full scale
Maximum safe heater current, 30% duty cycle on < 1 ms	7.5 mA
Couple output voltage (open circuit)	7 mV ± 12% at nominal heater current
Couple output impedance	less than 12 Ω
Couple resistance	8 Ω ± 10%
Maximum AC/DC reversal error at full scale	± 0.05% "A" Series and ± 0.005% "H" Series
Temperature coefficient	Nominally 2000 ppm/°C
Couple output voltage to heater (ground)	Normally should not exceed ± 10 volts Absolute maximum ± 50 V peak

Environment:

Operating temperature	4° to 40°C
Relative humidity	0 to 90%
Altitude	to 10,000 feet

Mechanical:

	1395A Series
Height	1 1/4 in (32mm)
Width	1 3/8 in (36mm)
Length (exclus. of connectors)	3 in (78mm)
Weight	5 1/2 oz. (156 gm)
Input connectors	Male BNC
Output connectors	3 pin Male Receptacle Type MS 3102A-10SL-3P
Optional Mating connector	3 pin Female Type MS3106A-10SL-3S
	Ballantine Part No. 31100020A



1395A SERIES
(UNBALANCED)

1395A SERIES
(BALANCED)

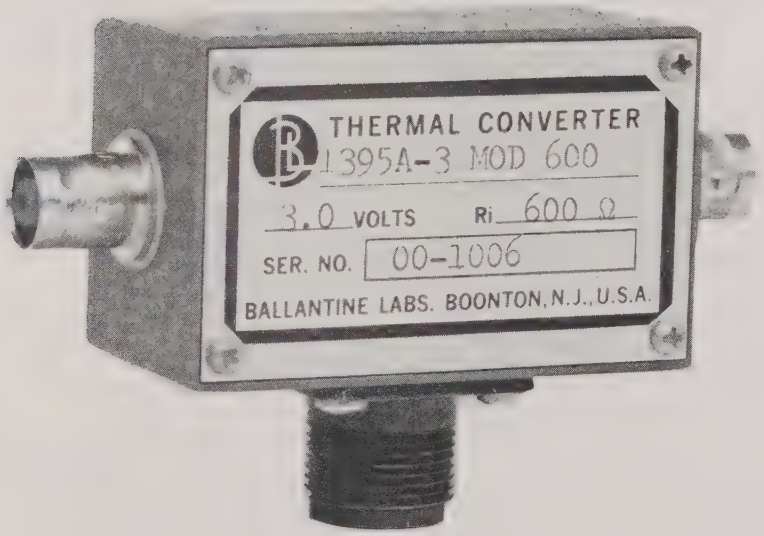
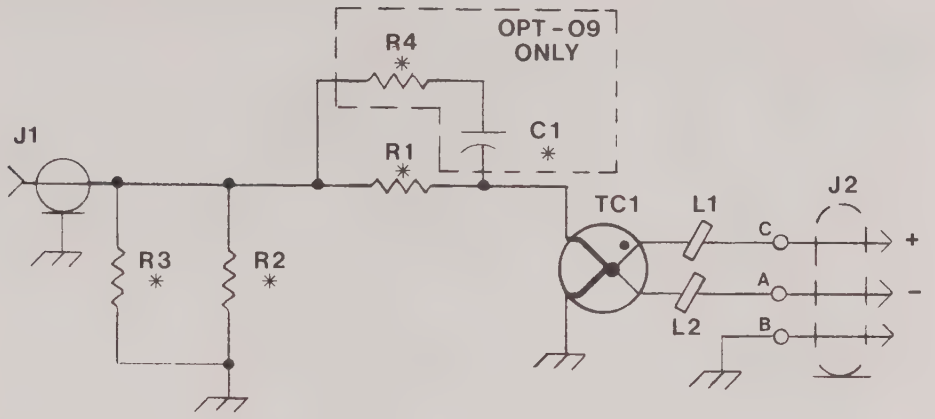


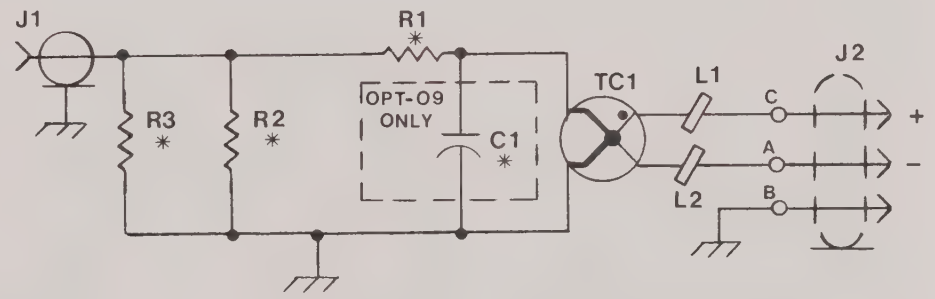
Figure 1-1. 1395A Series Thermal Voltage Converter



NOTES:

1. R1 & R2 SEE TABLE 2-1
2. R3 IS A FACTORY SELECTED VALUE
3. R4 IS A CAL ITEM AND C1 AND R4 ARE USED ONLY IN OPTION 09. (R4 IS ONLY APPLICABLE TO MODEL 1395A(H)-0.4 OPT.-09)

MODELS 1395A-0.4 and 1395A-1

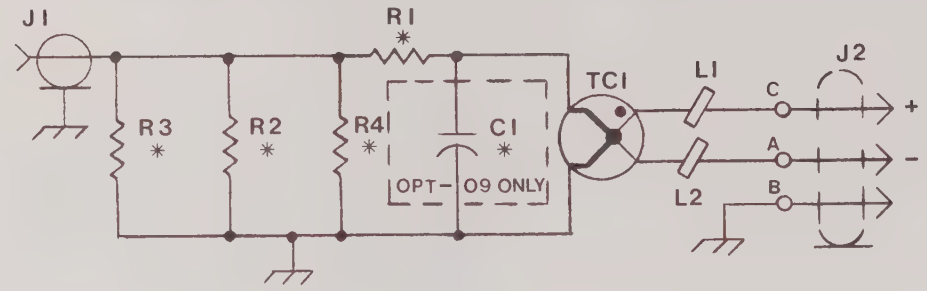


NOTES:

1. R1 AND R2 SEE TABLE 2-1
2. C1 IS A CAL ITEM USED ONLY IN OPTION 09
3. R3 IS A FACTORY SELECTED VALUE

MODEL 1395A-3

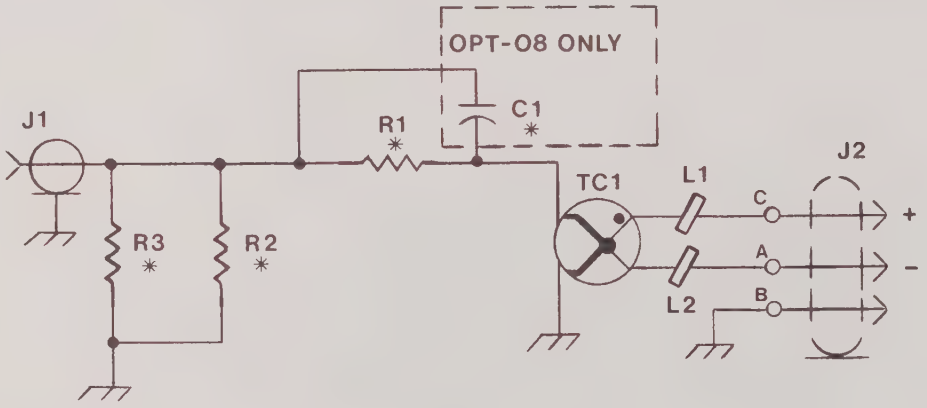
Figure 2-1. Schematic Diagrams



NOTES:

1. R1, R2 AND R3 SEE TABLE 2-1
2. R4 IS A FACTORY SELECTED VALUE
3. C1 IS A CAL ITEM USED ONLY IN OPTION 09

MODEL 1395A-6

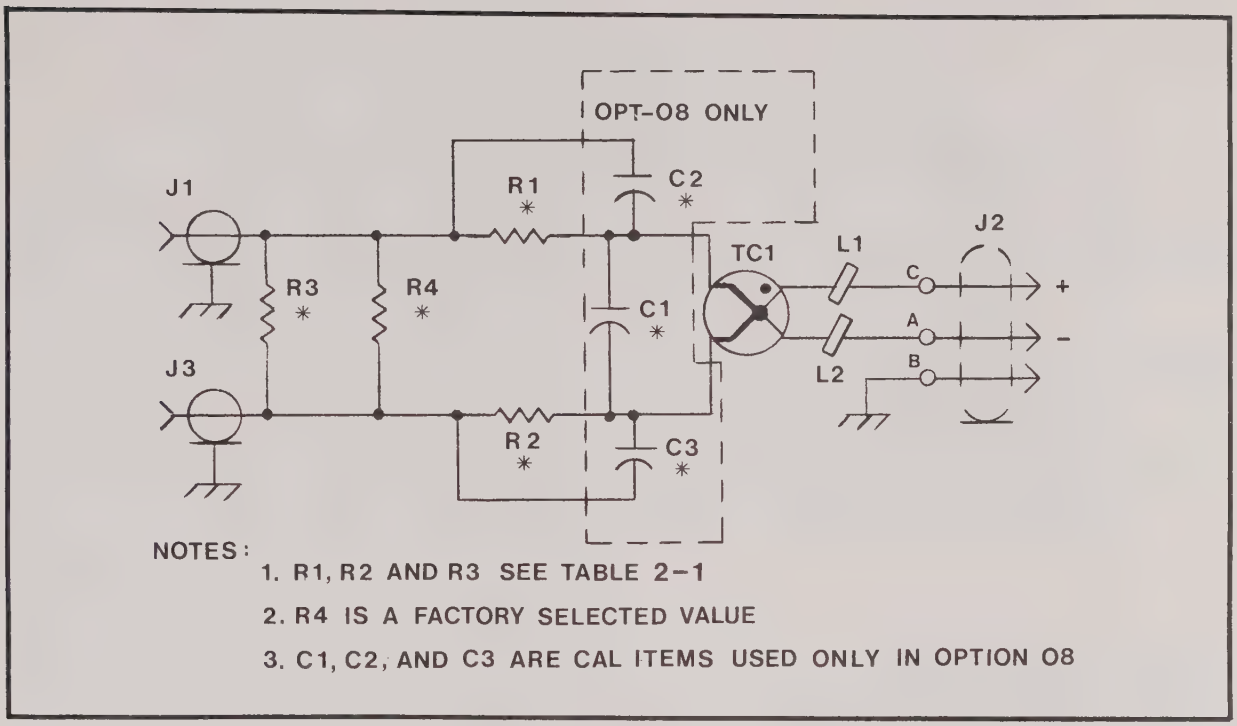


NOTES:

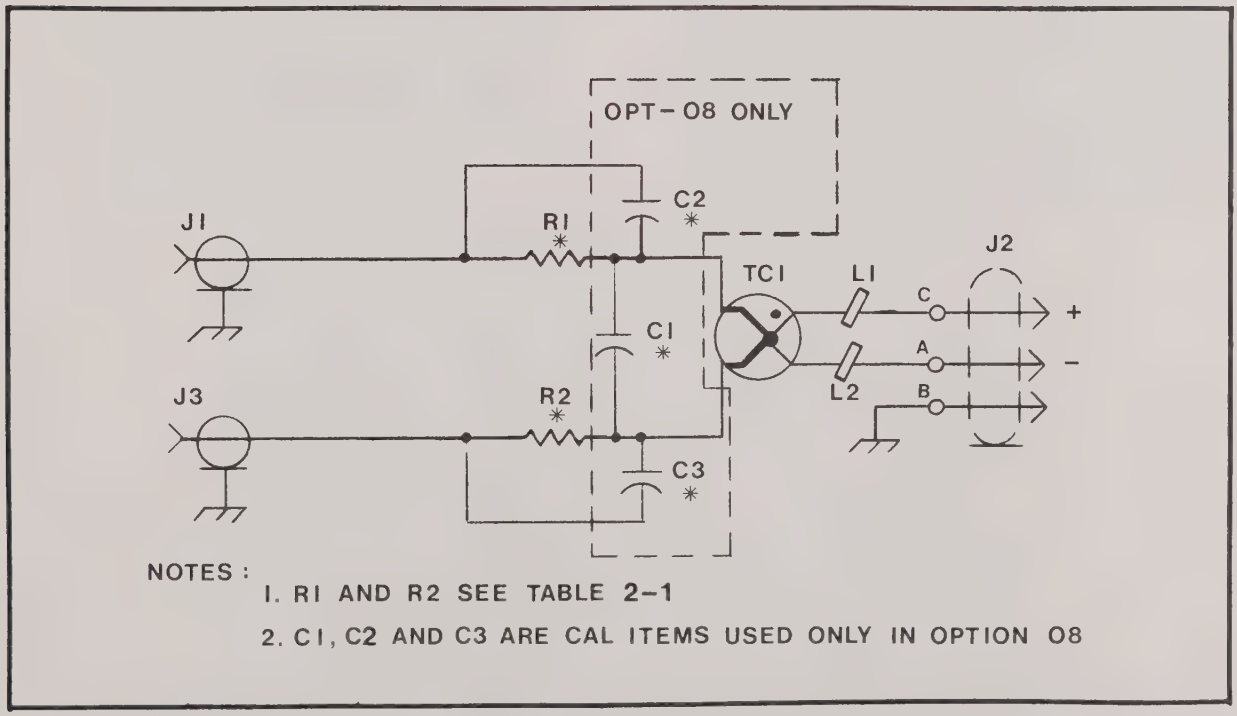
1. R1 AND R2 SEE TABLE 2-1
2. R3 IS A FACTORY SELECTED VALUE
3. C1 IS A CAL ITEM USED ONLY IN OPTION 08

MODELS 1395A-1 MOD75 and 1395A-1 MOD93

Figure 2-1. Schematic Diagrams - Cont'd



MODELS 1395A-1 MOD135 and 1395A-1 MOD150



MODEL 1395A-3 MOD600

Figure 2-1. Schematic Diagrams - Cont'd

TABLE 2-1. Model 1395A Series Resistor Values

MODEL	R1	R2	R3
1395A-0.4	10 Ω	107 Ω	N/A
1395A-1	110 Ω	66.5 Ω	N/A
1395A-3	511 Ω	54.9 Ω	N/A
1395A-6	1.1K Ω	107 Ω	107Ω
1395A-1 MOD75	110 Ω	121 Ω	N/A
1395A-1 MOD93	110 Ω	178 Ω	N/A
1395A-1 MOD135	80.6 Ω	80.6 Ω	294 Ω
1395A-1 MOD150	80.6 Ω	80.6 Ω	383 Ω
1395A-3 MOD600	255 Ω	255 Ω	N/A

AVAILABLE OPTIONS:

1. For 50 Ohm Units Option 09 — Calibration report and correction data points at 30 MHz, 70 mHz and 100 MHz.

2. For Balanced Units Option 08 — Calibration report and correction data points at 30 MHz and 50 MHz.

3. 1395H Series — The 1395H is similar to the 1395A Series in all respects except that vacuum thermoelement has ± 0.005% dc reversal error at full scale.

PART 2. CIRCUIT DESCRIPTION

2-1. GENERAL

A 90Ω UHF thermoelement which contains a heater filament and a thermoelectric junction, comprise the basic circuit of the thermal converter (figure 2-1). The ac current into the thermoelement heats the filament, and the thermoelectric junction generates a dc voltage proportional to the filament temperature. Therefore, the output voltage of the thermal converter is proportional to the input heating power. Resistors R4 and R5 limit the current through the thermoelement to 5 mA with maximum rated voltage. R1, R2 and R3 adjust the input resistance to 50Ω.

2-2. INPUT-OUTPUT RELATIONSHIP

The output voltage of the thermal converter is a function of input power. Therefore, the output varies as the square of the input. When the input is doubled, the output will be four times as great. When the input is halved, the output will drop to one-fourth.

For input changes of less than 3%, the input-output relationship is essentially linear; and the percent output change is equal to twice the percent input change. The following formula shows the relationship.

$$\% \text{ input change} = \frac{\Delta E_{dc}}{2E_{dc}} \times 100$$

where E_{dc} = thermal converter output voltage.

If the input lever is to be varied by more than 3% the actual input-output characteristic should be measured. This is best done at DC.

Since the thermal elements in the converter have a small thermal lag a ten second settling time is recommended for measurements requiring the utmost precision.

Figure 2-2 graphically illustrates the input-output relationship.

2-3. INPUT DYNAMIC RANGE

The dynamic range of Ballantine thermal converters is limited by the resolution and noise (at best about 100 nanovolts) of the system used to measure the output voltage of the couple. At maximum input level the output is only 7 mV. The conversion follows a square law relationship and the output therefore drops by 100 whenever the input is reduced by a factor of 10. Thus if 0.01% (one part in 10,000) input resolution is desired the minimum output voltage would only be 500 μ volts. This corresponds to an input voltage range somewhat greater than 3 to one. A dynamic range of 30 to one is possible when 1% resolution of input voltage (one part per hundred) is satisfactory.

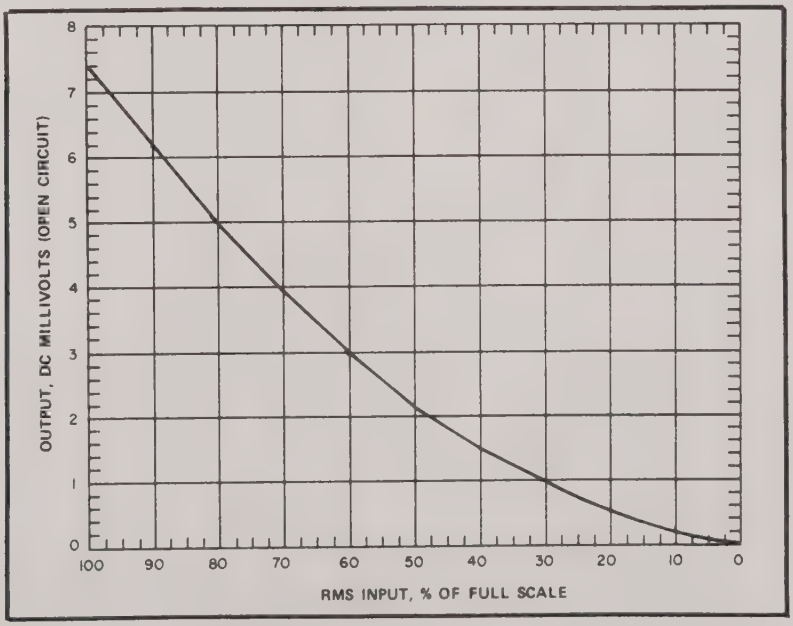


Figure 2-2. Input-Output Relationship

PART 3. OPERATION

3-1. PRECAUTIONS

Burnout of the thermocouple heater occurs so rapidly when the maximum peak power is exceeded that the rise in dc couple output voltage cannot be detected. Therefore it is necessary to take the following precautions to avoid overloading the thermocouple.

a. Be sure the voltage being measured is reduced to its lowest value before connecting or disconnecting the thermal converter input. Never allow intermittent wiring connections or poorly assembled connectors.

b. Provide a method for monitoring or controlling the voltage being measured by the thermal converter.

c. Do not change the frequency of the generator for voltage being measured without first reducing the voltage of the generator to its lowest value. **Caution:** *Most signal generators and oscillators produce large transient voltages when changing range.*

d. Do not allow the open-circuit dc couple voltage to exceed 7 millivolts (equivalent to 5 mA of heater current).

e. Non-sinusoidal waveforms, such as transients and pulse trains must have peak voltages which crest within the peak voltage and duty factor specifications.

f. Use precision 50 ohm attenuators ahead of the thermal converter when larger voltages or unknown signals are to be measured.

g. When larger voltages are to be measured than 6 V RMS or when higher impedance thermal converters inputs are required use

(1) The Ballantine 1600A (ATS) Auto-Balance transfer standard.

(2) The Ballantine Coaxial Thermal Converter Series 1394 200 ohms/volt DC to 100 MHz

h. Never exceed the breakdown voltage rating of ± 50 volts between couple and heater during set up of instrumentation and while making measurements. Ground all instrumentation.

3-2. OUTPUT MEASUREMENTS

The reliability of thermal converter measurements is based on the accuracy and resolution of the output measuring circuit. Figure 3-1 illustrates a stable and sensitive output monitoring circuit. With this circuit, resolution of an output change of 1.5 μV, or 0.01% of full scale, is readily achieved. The reference supply (mercury battery powered) generates a stable reference voltage, which opposes the thermal converter output with the dc null meter monitoring the difference voltage. The short term stability of the battery is good enough for the thermal converter output changes to be read directly on the null meter, without taking reference voltage drift into consideration. Another output measuring system providing stability and accuracy would be a stable high resolution digital voltmeter or differential voltmeter. To resolve an input change of 1% of full scale, the output monitor should be able to resolve 150 μV; for input changes of 0.1% of full scale, it should be able to resolve 14 μ V. Battery operated instruments are recommended to avoid grounding problems and other power line effects. It is not uncommon to make these measurements in a screen room.

When building the reference supply shown in Figure 3-1, utilize a mercury battery and wirewound resistors. Use 10 turn or 20 turn high resolution wirewound potentiometers, and a switch with contacts exhibiting low thermoelectric effects. After constructing the reference supply, mount it in a shielded container and permit the battery to age in the circuit for approximately one week. The longer the battery is allowed to age, the better its short term stability will be.

A constant ambient temperature should be maintained while making all thermal converter measurements. (25°C + 2°C is recommended) Since the thermoelement responds to the heating effect of the input signal, a change in ambient temperature would cause a change in the thermal converter output.

3-3. FREQUENCY RESPONSE MEASUREMENTS

A test setup for making accurate frequency response measurements is shown in figure 3-1. The following steps describe the measurements.

a. Set the oscillator and reference supply output levels to minimum.

b. Connect the test equipment as shown in figure 3-1 keeping the connecting cable between the oscillator and thermal converter as short as possible. Use shielded low noise cables and ground the reference voltage supply to the chassis ground of the null meter.

c. Adjust oscillator amplitude for an indication of about 7 mV on the null meter.

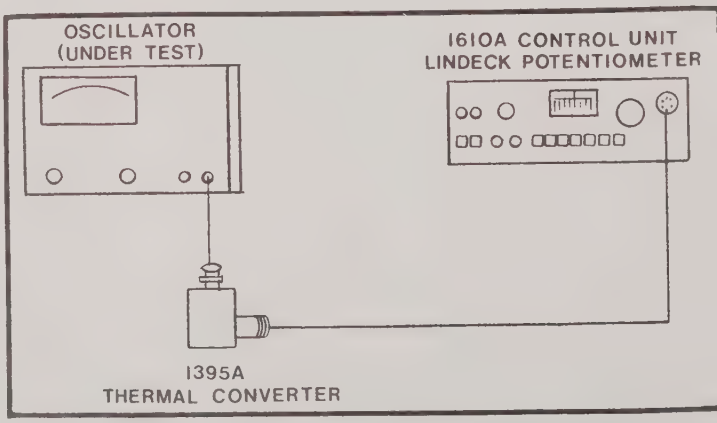


Figure 3-1. Frequency Response Measurements

CAUTION

Do not exceed the rated input of the thermal converter. Always reduce the input before changing frequency range of circuit under test. Any overload or high voltage transient may destroy the thermoelement. Ground test equipment and do not exceed couple to heater voltage rating.

d. Adjust the reference supply for a null indication within 1 μ V. Once a null is obtained, do not readjust the oscillator or reference supply outputs.

e. Change the input frequency and observe thermal converter output changes. Remember that the percent of converter output change read on the null meter equals twice the percentage input signal level change.

3-4. GENERATING AN ACCURATE CALIBRATION SIGNAL

The test setup shown in figure 3-2 provides a test signal that may be used for both frequency response and absolute value calibration at any frequency within the thermal converter range. The dc standard provides the absolute value voltage reference, and the test oscillator generates the ac calibration signal. When S1 is set to the dc position and output of the DC Voltage Standard is set to the desired calibration voltage, the reference supply is adjusted for a null indication on the Null Meter. When S1 is switched to the AC position, the oscillator output amplitude is adjusted to re-establish a null indication. This sets the RMS value of the oscillator output equal to the DC Voltage Standard output. The oscillator output signal is used for the instrument under test.

3-5. DC REVERSAL ERROR

DC inputs of opposite polarity will produce slightly different outputs from the thermal converter. This difference in thermocouple outputs for positive or negative input signals is called the DC reversal error. Sinusoidal input signals have equal energy content in positive and negative half cycles. These sine wave signals automatically average DC reversal errors in the thermocouple. Nevertheless, unidirectional signals such as pulse trains, switching transients, and sine waves with dc offset will primarily have energy content in one polarity and therefore thermal converters require DC reversal error correction. The DC reversal error is less than 0.05% and does not affect most measurements, but it should be considered to achieve maximum accuracy. For best DC reversal error performance specify 1395H Series.

Instruction for correcting precise measurements for DC Reversal Error are given in the following calibration procedure in Part 4.

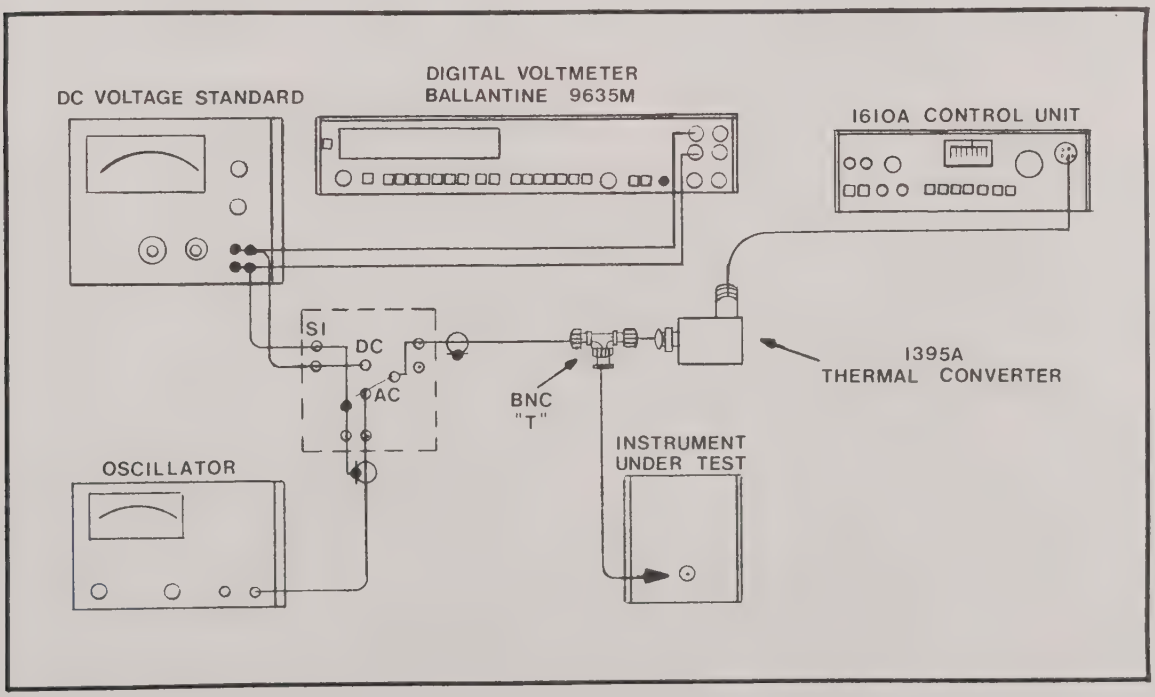


Figure 3-2. Generation of a Precise Test Signal

Table 4-1. Recommended Test Equipment

Qty.	Item	Recommended	Alternate
2	DC Null Meter/DC Micro Voltmeter 15 uV to 1500 volts	Ballantine 1610A	GR1807
1	AC Voltage Standard	Fluke 5200A	Ballantine 421A (10mA)
1	Precision Digital Voltmeter 100 uV resolution on 1 volt scale Accuracy ± 0.01%	Ballantine 9635M	Fluke 8600
1	Oscillator 10 Hz to 10 MHz 3 volts into 50 Ω	HP 651B	----------
1	Power Supply DC, 0-10 volts, 0 to 1 amp	Power Designs 1515B	HP6213A
1	Impedance Bridge	General Radio Type 1608A	----------
1	50 ohm Feed thru Termination	Ballantine 12630A	HP11048B
1	AC Voltmeter, 1 mV full scale 10 Hz to 10 MHz	Ballantine 3045A	Ballantine 3056A
1	BNC "T" Connector UG 274/C	Ballantine 12619A	----------
1	NBS Certified Thermal Converter	Ballantine 1395A-0.4	----------
1	NBS Certified Thermal Converter	Ballantine 1395A-1	----------
1	NBS Certified Thermal Converter	Ballantine 1395A-3	----------
1	NBS Certified Thermal Converter	Ballantine 1395A-6	----------

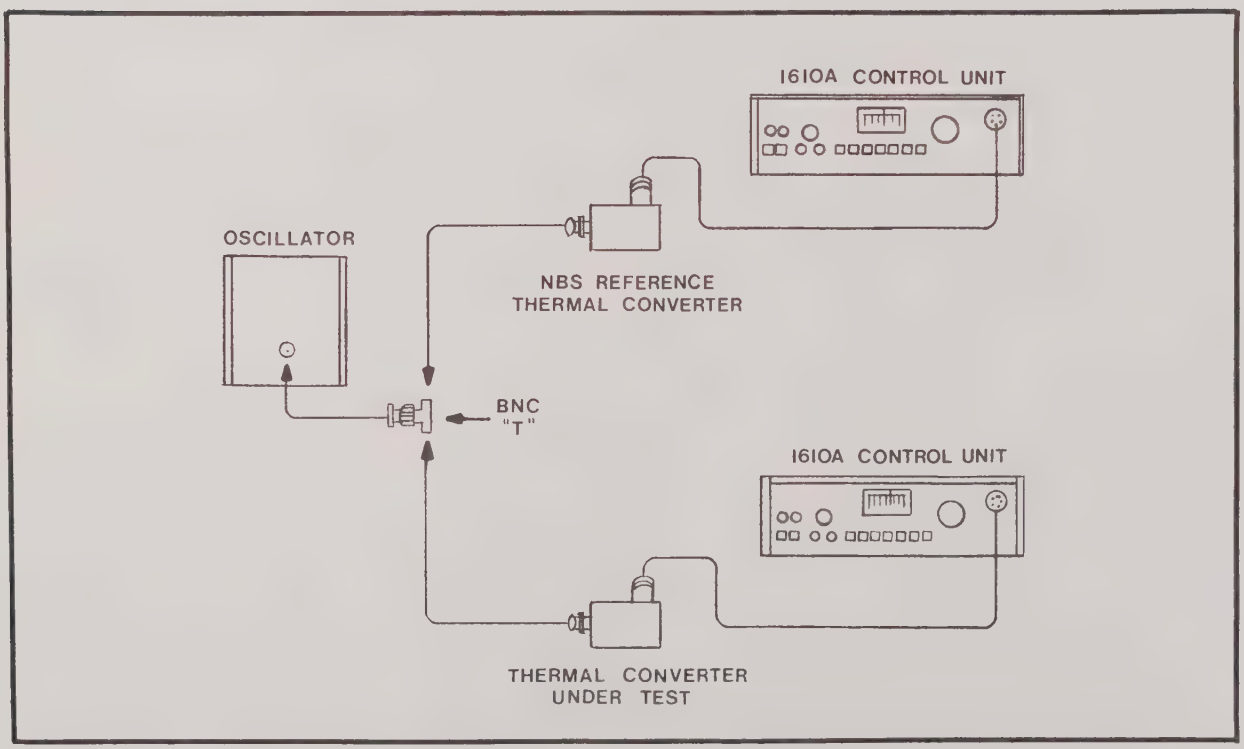


Figure 4-1. Thermal Converter Calibration

PART 4. CALIBRATION

4-1. CALIBRATION PROCEDURE

The steps that follow, describe a procedure for generating a 1-volt calibration signal within the thermal converter specifications. Steps c through h describe the procedure for compensating DC reversal error.

NOTE

A thermal converter is a true RMS converter responsive to the true heating value of the input signal. Average responding circuits react differently to harmonic and waveshape distortion. Calibration is normally performed with pure sinusoidal waveforms and any noise, waveshape error or harmonic distortion present will create a calibration error between the thermal converter and the instrument under test. Note that the thermal converter always measures the entire energy content (heating value) of the input calibration signal including harmonics, noise energy and non-harmonically related distortion. Use of a low distortion test oscillator is required to avoid possible calibration error of the instrument to be checked.

CAUTION

Never exceed the couple to heater breakdown voltage rating.

a. Set the test oscillator and DC Voltage Standard output level to minimum.

b. Connect the test equipment and instrument under test as shown in figure 3-2. Keep all connecting cables as short as possible. Perform these tests in a low electrical noise or shielded environment. Always ground test equipment.

c. Set S1 (in figure 3-2) to DC, and the DC Voltage Standard output to +1.000 V ±0.01%.

d. Adjust the reference supply for a null indication on the null meter within less than ±1 μV. Record the null meter indication. Once null is obtained, do not readjust reference supply output.

e. Reverse the polarity of the DC Voltage Standard output and again record the null meter reading.

f. Add the null meter reading of steps d and e.

g. Divide the sum of step f by 2. This averages the DC reversal error of the thermal converter.

h. Readjust the reference supply until the null meter indicates the average reading determined in step g.

i. Set S1 to AC and the oscillator frequency to 1 KHz. Set the oscillator output so that the null meter indication equals the indication recorded in step h. This sets the oscillator output to 1 V RMS.

j. Record the reading and error of the instrument under test. This instrument will usually be a passive device such as an AC voltmeter, wave analyzer, spectrum analyzer etc.

CAUTION

Do not change the oscillator frequency range without first lowering oscillator output. Switching transients may destroy the thermoelement.

k. Adjust the frequency to the desired test frequency. Then readjust the oscillator output amplitude for the same null meter indication obtained in step h. Record the reading and error of the instrument under test.

l. Repeat steps j and k for each test frequency desired.

4-2. THERMAL CONVERTER CALIBRATION

The test setup for calibrating a thermal converter to an NBS calibrated reference thermal converter is shown in figure 4-1. With this setup, the thermal converter can be calibrated to within ± 0.05% of the reference. The steps that follow describe the calibration procedure.

a. Set the test oscillator and both reference supply outputs to minimum.

b. Connect the test equipment up as shown in figure 4-1. Keep connecting cables to thermal converters as short as possible. Operate in a low noise or shielded environment. Consider the use of battery operated instrumentation to avoid ground loop error and power line disturbances.

c. Adjust the amplitude of the oscillator for an indication of approximately 7 mV on both null meters. Set the oscillator frequency for 1 KHz.

d. Adjust the reference supplies for a null indication on the respective null meters.

e. Change the oscillator frequency to 5 Hz.

f. Readjust the oscillator amplitude for a null indication on the null meter connected to the NBS reference thermal converter. The null meter connected to the thermal converter under thest should indicate the same as the reference null meter. If not, record the error and remember that the percent change in the thermal converter output is equal to twice the percent change in the input. (i.e. 1% change in output equals ½% input signal change).

g. Repeat steps e and f at 50 Hz, 500 Hz, 5 KHz, 50 KHz, 500 KHz, 1 MHz, 6 MHz, 8 MHz, 10 MHz. In each case, record the error.

h. Use the error data collected in steps e to g, make corrections whenever using the thermal converter. If the difference between the reference thermal converter and the thermal converter under test is greater than the specifications in the "with reference to standard" column in table 1-1, the thermal converter is not operating properly. Refer to repair instructions in paragraph 5-1.

i. The calibration of the thermal converter should be checked against an NBS reference thermal converter at least once every six months during the first year, and once a year thereafter.

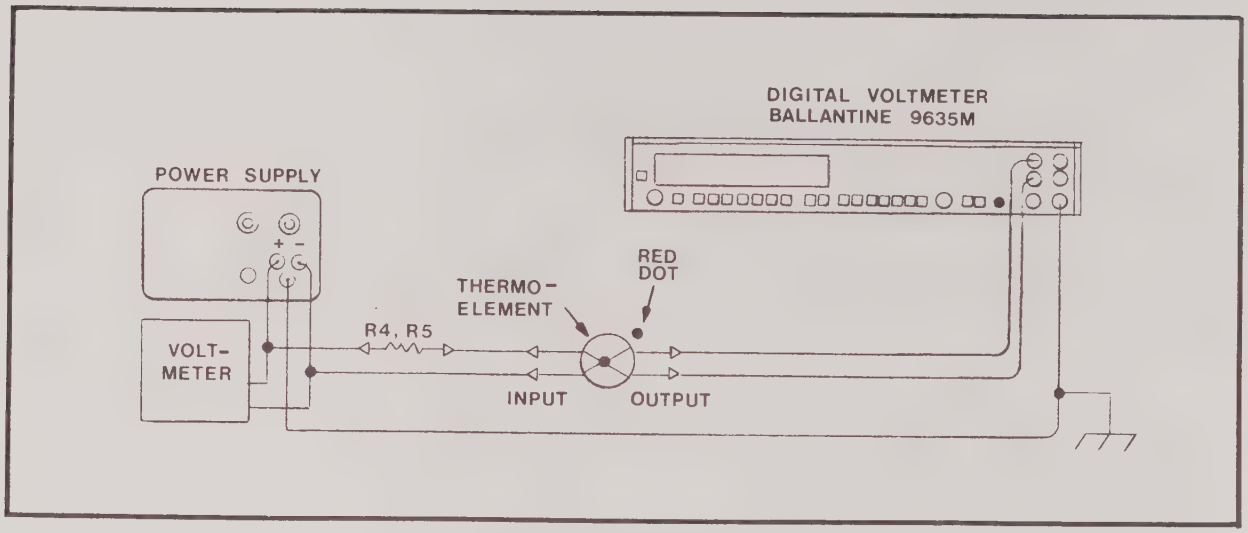


Figure 5-1. Resistor Selection

(Selection of R4 or R5 or a single equivalent resistor in series with the heater of the thermal converter.)

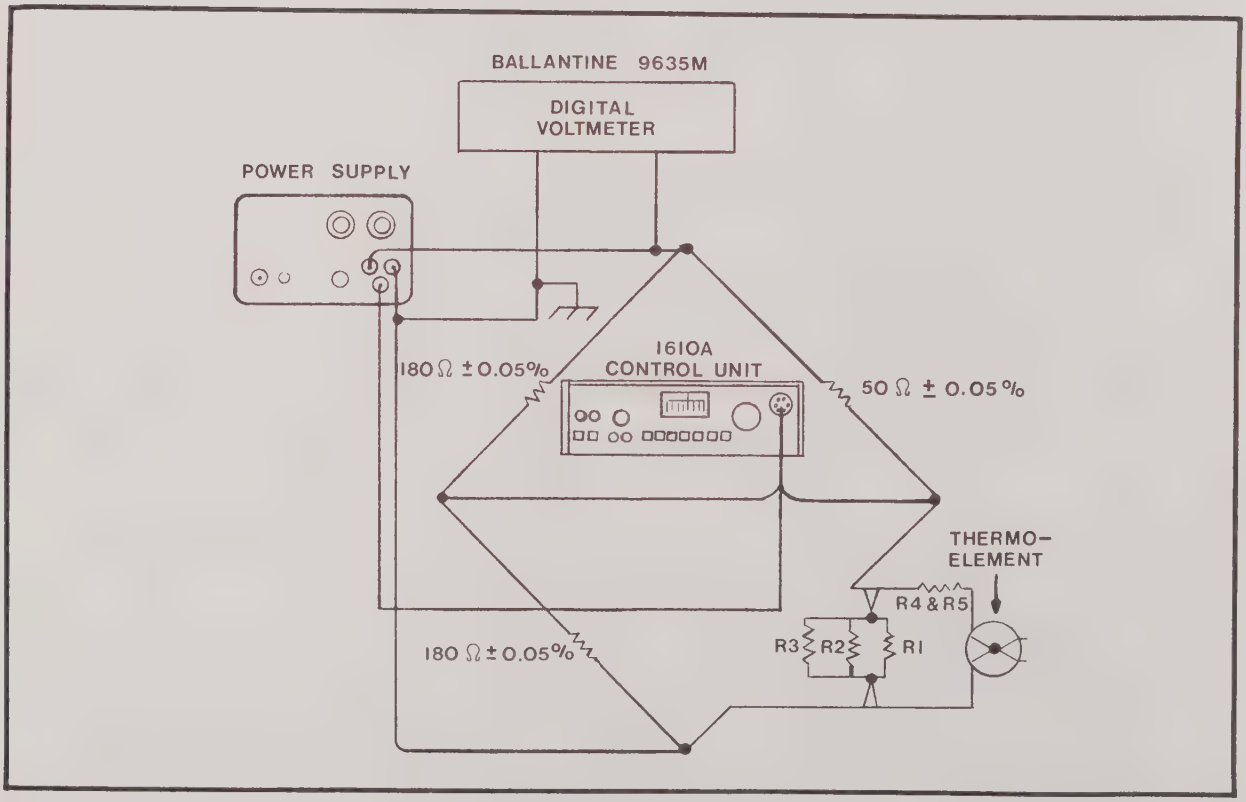


Figure 5-2. Selection of R3

PART 5. REPAIR AND MAINTENANCE

5-1. REPAIRING THE THERMAL CONVERTER

If the thermal converter is out of calibration below 10 MHz or it has no output, then the UHF thermoelement should be replaced. Since the values of R3 and R4 and R5 in the circuit (see figure 2-1) depend on variations in thermoelement characteristics, they must always be re-selected when the thermoelement is replaced.

5-2. SELECTION OF R4 AND R5

Current through the thermoelement is adjusted to 5 mA with a full scale input by R4 and R5. In the Model 1395A-3, R4 and R5 have a total value of about 510 Ω . In the Model 1395A-1, R4 and R5 have a total value of about 110 Ω , and in the Model 1395A-0.4, R4 and R5 are deleted. R4 and R5 should always be 1/2 watt (40°C) ± 1% precision film resistors.

The test setup for selecting R4 and R5 is shown in figure 5-1. The power supply provides a known input, and the DC voltmeter monitors the thermoelement output. R4 and R5 are selected to adjust the thermoelement output to 6.5 mV with 90% full scale input. Proceed as follows:

a. Turn the power supply off and connect it to the thermoelement, DC voltmeter an an initial value of series resistor.

-For Model 1395A-1 the series resistance is approximately 110 Ω . This may be one single resistor or two each 54.9 Ω resistors in series as R4 and R5.

-For Model 1395A-3 the series resistance is approximately 505 Ω to 570 Ω . A single 510 Ω resistor may be used or a 261 Ω and a 244 Ω resistor connected in series may be used as R4 and R5.

—For Model 1395A-6 the series resistance is approximately 1100Ω and a single resistor is usually employed.

b. Using the voltmeter as a monitor, slowly adjust the power supply output to 0.9 volts for Model 1395A-1 or 2.85 volts for Model 1395A-3 and 5.4 volts for Model 1395A-6.

c. Connect the voltmeter to thermoelement output and observe a 6.5 mV reading. If the output is high, increase the value of R4 or R5; if the output is low, decrease the value of R4 or R5.

An alternative method of selecting R4 and R5 is to assume that the thermoelement resistance is 90 Ω and select R4 and R5 as 510 Ω in series for the Model 1395A-3 and 110 Ω in series for the Model 1395A-1 and 1100 Ω for Model 1395A-6. If this method is used, the nominal 7.5 mV output may be high or low as much as 10% which is normally of no consequence.

5-3. SELECTION OF R3

a. R1 and R2 are connected in parallel as illustrated in the schematic diagram, figure 2-1.

b. R3 is selected so that when it is in parallel with R1 and R2 and with the series combination of R4, R5 (in Models 1395A-1, 1395A-3 and 1395A-6) and the thermal element, produce an input resistance of 50 ± 0.15 ohms.

c. This selection method is used for Models 1395A-1, 1395A-3 and 1395A-6 where R4 and R5 are used.

d. Resistors R1, R2, R4, and R5 are ½ watt, ±1%, (40°C), precision film resistors. Selected resistor (s), R3 may be a ¼ watt, ±1%, precision film resistor or a ½ watt carbon composition ± 5% resistor.

A bridge for selecting R3 is shown in figure 5-2. With the DC power supply drive voltage set so that the thermoelement operates at approximately its rated full scale input of 5 mA, R3 can be adjusted for null. Proceed as follows:

a. Set the power supply to off, and construct the bridge shown in figure 5-2.

b. Connect an initial value of R1 as shown in figure 5-2. For Model 1395A-6 and 1395A-3 use two 113 Ω resistors in parallel and a selected value approximately 1.82k Ω ; 1395A-1 use a 140 Ω and a 133 Ω resistor in parallel and a selected value of approximately 47k Ω ; for 1395A-0.4 use a 122 Ω and a 249 Ω resistor plus a selected resistor value of approximately 2.7k Ω .

c. Adjust the power supply drive voltage to the appropriate value listed below (which will run the respective thermoelement at 60 to 80% of rated current).

1395A-0.4	0.6 volts
1395A-1	1.5 volts
1395A-3	4.5 volts
1395A-6	9.0 volts

d. Vary resistor R1 to achieve a null indication on null meter. The maximum deviation from null should be as follows:

1395A-0.4	± 150 uV
1395A-1	± 375 uV
1395A-3	± 1.25 mV
1395A-6	± 2.50 mV

5-4. PROCEDURE FOR AC CALIBRATION OF INPUT IMPEDANCE OF THERMAL CONVERTER

a. Connect equipment as illustrated in figure 5-3.

CAUTION

Do not connect thermal converter to be calibrated until after step discompleted.

b. Set up Impedance Bridge (General Radio 1608A) resistive impedance.

c. Adjust test oscillator for output frequency of 10 KHz.

d. Set RMS output amplitude of test oscillator for appropriate input for thermal converter to be tested (i.e. 1395A-0.4 - 0.45 volts; 1395A-1 - 1.0 volts; 1395A-3 - 3.0 volts; 1395A-6 - 3 volts or 6 volts if high power low distortion oscillator is used) as indicated on AC Voltmeter, Ballantine Model 323, with a 50-ohm feedthru termination in series with voltmeter input.

e. Disconnect AC voltmeter and connect thermal converter to be tested to UNKNOWN terminals on impedance bridge.

f. Tune impedance bridge for null indicated on NULL meter of bridge. Impedance readout should be 50 ±0.15 ohms. If this readout is not obtained, perform the calibration procedures given in paragraph 4-2, and carefully redress the component in the thermal converter as shown in figure 5-4 then repeat this procedure.

5-5. INSTALLATION OF THERMOELEMENT AND RESISTORS

The spatial orientation of the components within the thermal converter is critical. Placing the components improperly may cause serious degradation of the higher frequency response.

Field replacement of the thermocouple used in the Model 1395A is possible provided that leads are cut and shaped to conform exactly to the unit just removed.

CAUTION

Utilize an adequate heat sink when making soldering connections to the thermoelement. Excessive or extended heating will change thermoelement characteristics. Use a grounded soldering iron with 3 wire power cord to avoid exceeding the couple to heater breakdown voltage rating.

a. Keep all leads as short as possible.

b. Ensure proper component mounting

c. Avoid bending thermoelement leads any more than is absolutely necessary as excessive bending may weaken glass seal and reduce isolation.

d. Red (positive) lead should be connected to thermoelement output lead marked with a red dot.

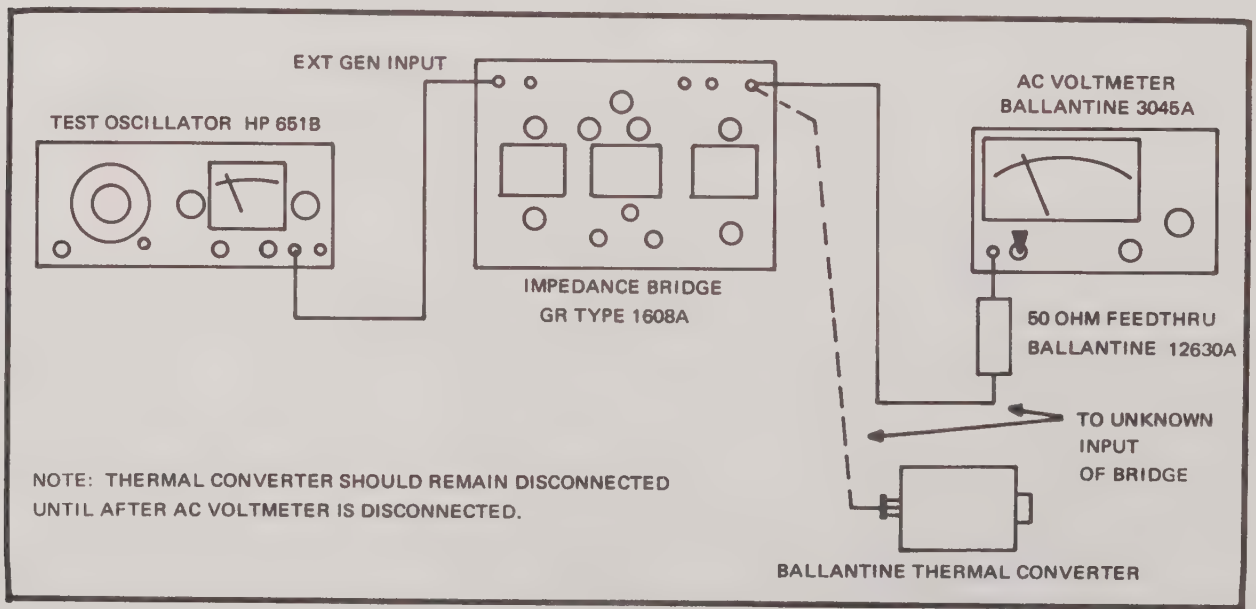


Figure 5-3. AC Calibration of Input Impedance

PART 6. REPLACEMENT PARTS

Model	Part No.	Symbol	Description
1395A-0.4	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13111-0A	R1	RFF 10.0 500.0MW F
	12-13194-0A	R2	RFF 107.0 500.0MW F
1395A-1	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13189-0A	R1	RFF 110.0 500.0MW F
	12-13190-0A	R2	RFF 66.5 500.0MW F
1395A-3	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13191-0A	R1	RFF 511.0 500.0MW F
	12-13192-0A	R2	RFF 54.9 500.0MW F
1395A-6	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13193-0A	R1	RFF 1.10K 500.0MW F
	12-13194-0A	R2	RFF 107.0 500.0MW F
	12-13194-0A	R3	RFF 107.0 500.0MW F
1395A-1 MOD75	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13189-0A	R1	RFF 110.0 500.0MW F
	12-13195-0A	R2	RFF 121.0 500.0MW F
1395A-1 MOD93	31-10227-0A	J1	CON BNC MALE FLNGE
	31-10001-0A	J2	CON 3 PIN MALE REC
	12-13189-0A	R1	RFF 110.0 500.0MW F
	12-13196-0A	R2	RFF 178.0 500.0MW F
1395A-1 MOD135	31-10228-0A	J1	CON BNC FEM
	31-10001-0A	J2	CON 3 PIN MALE REC
	31-10228-0A	J3	CON BNC FEM
	12-12971-0A	R1	RFF 80.6 500.0MW F 50PPM
	12-12971-0A	R2	RFF 80.6 500.0MW F 50PPM
	12-13188-0A	R3	RFF 294.0 500.0MW F
1395A-1 MOD 150	31-10228-0A	J1	CON BNC FEM
	31-10001-0A	J2	CON 3 PIN MALE REC
	31-10228-0A	J3	CON BNC FEM
	12-12971-0A	R1	RFF 80.6 500.0MW F 50PPM
	12-12971-0A	R2	RFF 80.6 500.0MW F 50PPM
	12-13197-0A	R3	RFF 383.0 500.0MW F
1395A-3 MOD600	31-10228-0A	J1	CON BNC FEM
	31-10001-0A	J2	CON 3 PIN MALE REC
	31-10228-0A	J3	CON BNC FEM
	12-13187-0A	R1	RFF 255.0 500.0MW F
	12-13187-0A	R2	RFF 255.0 500.0MW F
All Models	46-10000-0A	L1	FRB FERRITE BEAD
	46-10000-0A	L2	FRB FERRITE BEAD
	27-07946-1A	TC1	THC 5MA 0.04% REV.
"H" Series	27-10000-1A	TC1	THC 5MA .005% UHF

OPTIONAL ACCESSORIES

Model	Part No.	Description
All Models	12257A	Low noise connector and cable assembly
All Models	13941A	Accessory connector kit. Includes cable and various coaxial adapters.
All Models	10130A	3 pin mating "MS3106-A-10SL-3S" output cable connector with clamp and bushing

SECTION 4.

1396A Series

50 Ohm

Thermal Voltage Converters

1396A Series
Thermal Voltage Converters

PART 1. GENERAL INFORMATION

1-1. INTRODUCTION

The Ballantine TVC's 0.1–1 GHz is a thermal voltage converter with a "T" connector built onto the front end. These instruments are used as a standard source of known rf voltages up to 1 GHz from 0.25 to 7 volts in three ranges. They can be used to calibrate accurately any type of voltmeter that can be attached to their output. A device that can detect the output of a thermocouple is needed to operate this instrument (1-10 mV dc).

1-2. SPECIFICATIONS

Model	Voltage Range
1396A-1	0.2 - 1.3 V (to 1 GHz)
1396A-2.4	0.48 - 3.2 V (to 1 GHz)
1396A-7	1.4 - 9.4 V (to 1 GHz)

1396H Series: Same as above, but supplied with ± 0.005% reversal error thermoelement. Never exceed 5 mA heater current to maintain dc reversal error specification.

Frequency range: 0.1 – 1 GHz

Accuracy: 1 percent from 0.1 - 1 GHz of the rf-dc differenence at the end of the female type N connector connected into the output of the TVC.

RF input connector: Type N male

RF output connector: Type N male

DC output connector: MS 3102A-105L-3P

Input VSWR: When terminated with 50 ohm voltmeter
< 1.3 to 500 MHz
< 2.2 to 1 GHz

Weight: 1 V - 2 lbs. 13 oz. (1.276 Kg)
2.4 V - 2 lbs. 13 oz. (1.276 Kg)
7 V - 2 lbs. 4 oz. (1.021 Kg)

Shipping: 12 lbs. (5.443 Kg)

1-3. INSTRUMENT IDENTIFICATION

The model number is divided into four parts (1) Ballantine (mgf.) (2) TVC (type of instrument), (3) frequency range and (4) maximum operating voltage.

PART 2. CIRCUIT DESCRIPTION

Each instrument consists of a frequency compensated thermal voltage converter (TVC) with a "T" connector built-in. The basic diagram is shown in figure 2-1.

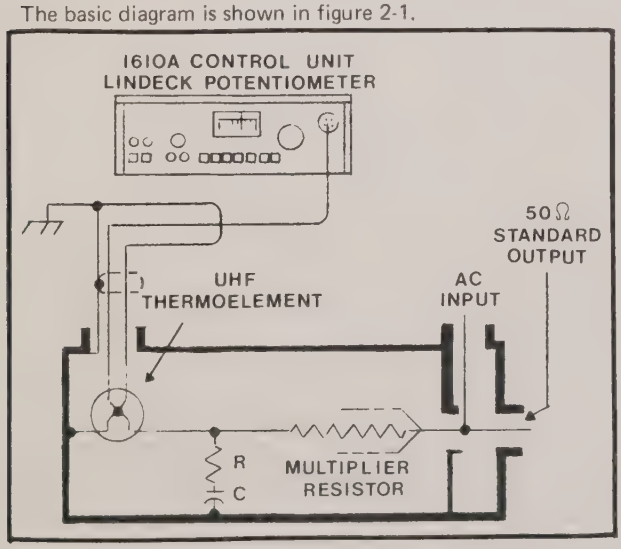


Figure 2-1. TVC 0.1 – 1GHz.

Referring to figure 1 the rf voltage is measured at the reference plane indicated. This plane coincides with the end of a type "N" female connector connected into the standard output. This rf voltage is detected by the TVC which is made up of a thermoelement (TE) detector, a dropping resistor R and a compensation network R_C and C_C. The voltage at the voltage reference plane is dropped across R and the heater of the TE. The thermocouple output of the TE is a function of the voltage drop across its heater and therefore of the reference voltage.

The rf-dc difference technique is used in the operation of these units. This technique consists of measuring the percent difference between the rf output when rf is applied and the dc output when dc is applied for the same TE output. This difference is not a function of temperature or level.

The compensating network made up of R_c and C_c is used to maintain the rf-dc difference within twenty percent over the entire frequency range up to 1 GHz. The actual rf-dc difference is determined by comparison with the national (NBS) reference standard.

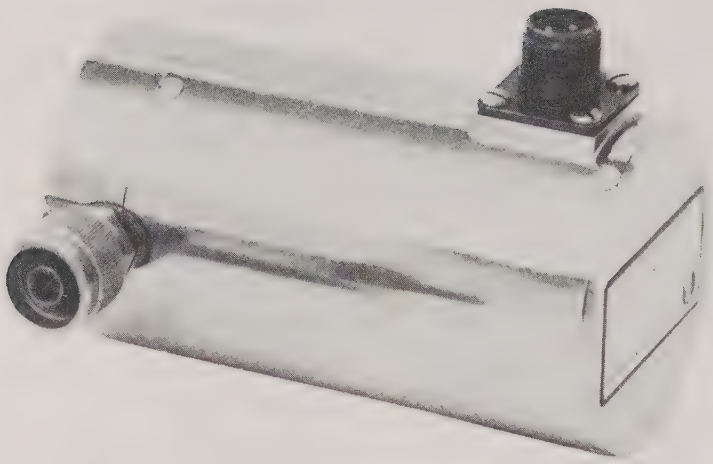
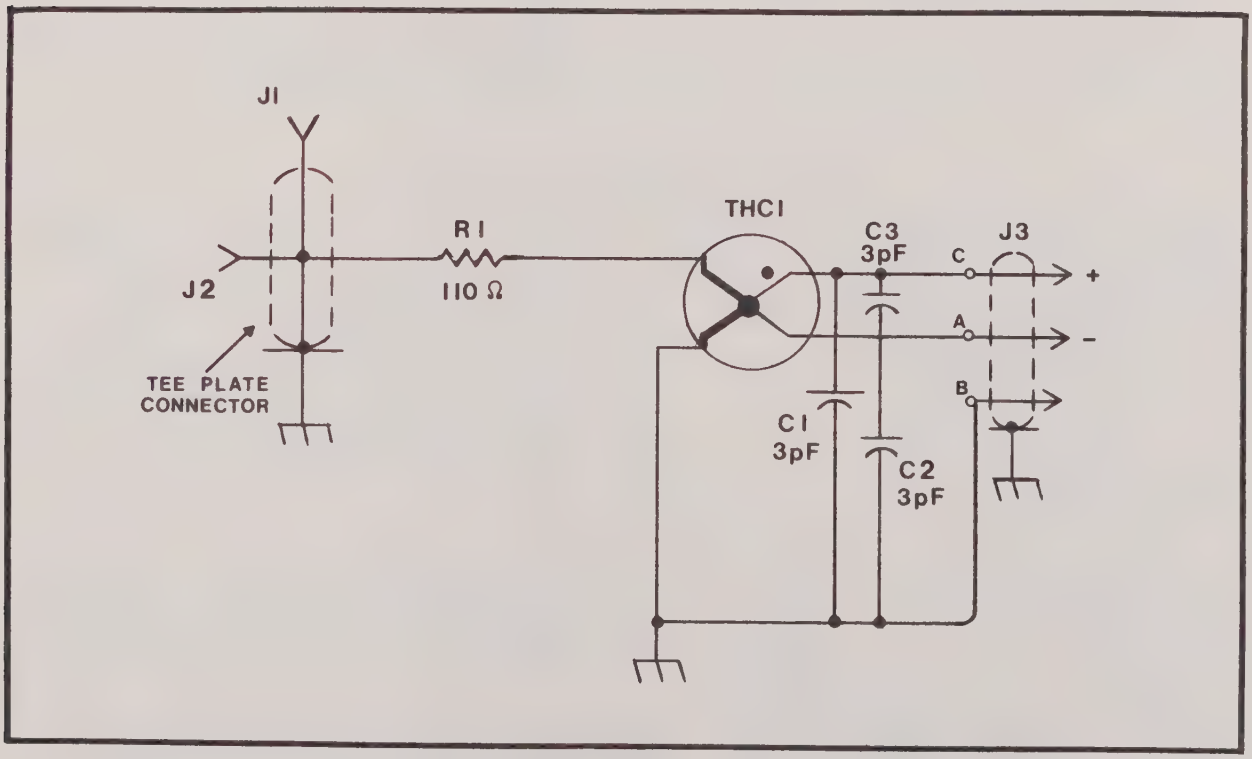
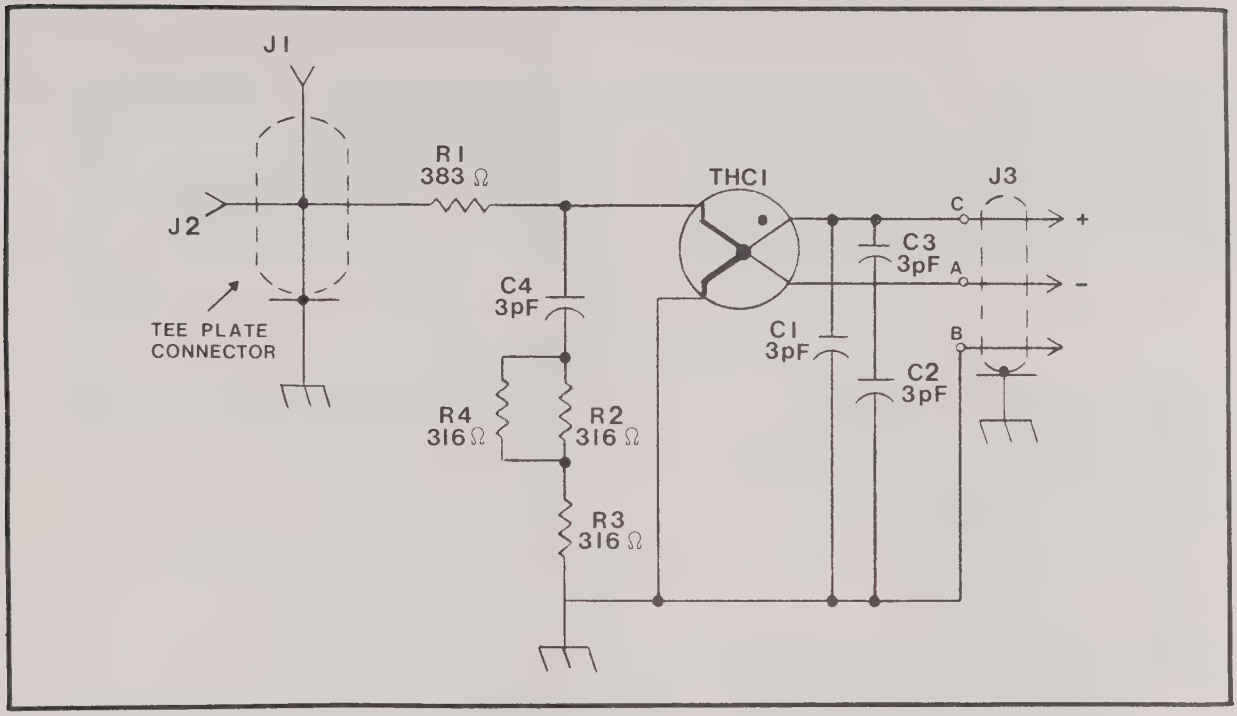


Figure 1-1. 1396A Series Thermal Voltage Converter

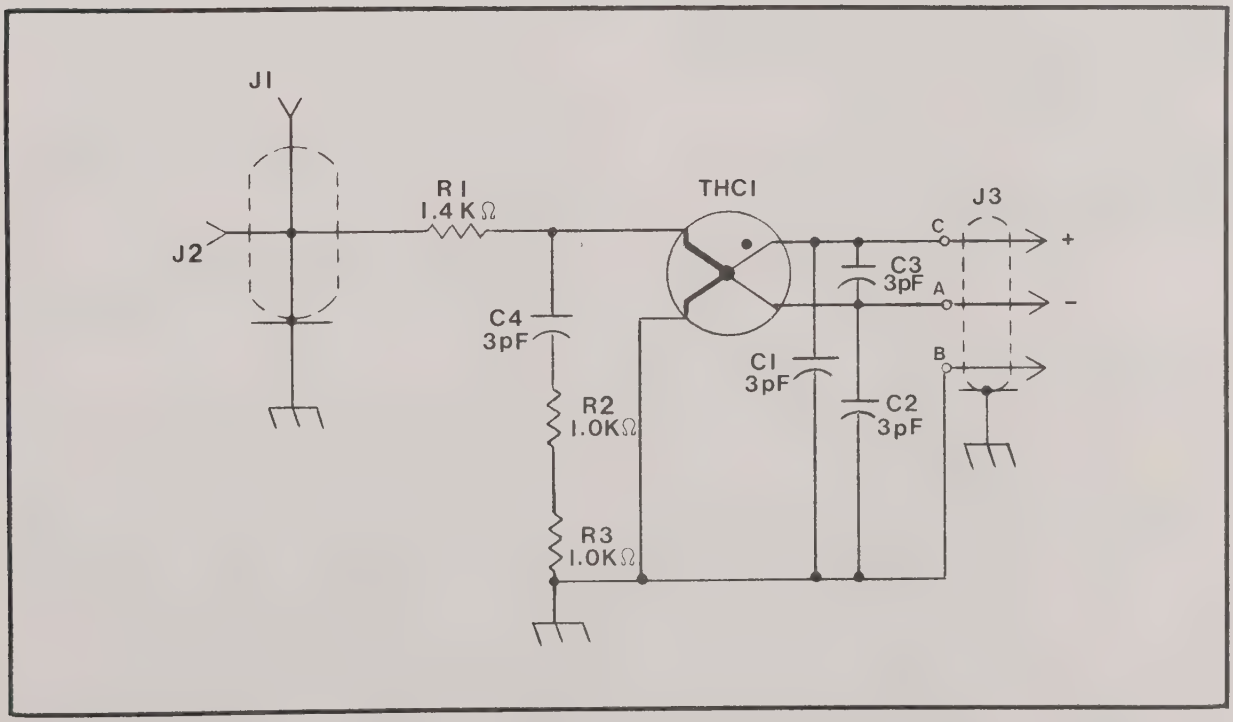


Model 1396A-1

Figure 2-2. Schematic Diagrams



Model 1396A-2.4



Model 1396A-7

Figure 2-2. Schematic Diagrams - Cont'd

The critical parts of these units, should replacement be required, are: (1) exact type TE must be used, (2) the resistance R must be carbon film of the same dimension as the original and have no spiraling, (3) R_c and C_c must be of the same types as used in the original, (4) inside dimension of the case and "T" must be the same as original, and (5) the placement of the TE, R, R_c and C_c are all critical and must be replaced exactly as the original.

These devices could be used at any frequency from 20 Hz to 1 GHz but have initially been calibrated at only 100, 300, 500, 700 and 1000 MHz.

PART 3. OPERATION

3-1. RF VOLTMETER CALIBRATION

The following procedure should be used to calibrate rf voltmeters in the voltage range from 0.25 to 7 volts over a frequency range of 0.1 to 1 GHz.

Setup system as outlined in figure 3-1.

RF Generator Specifications:

Frequency range: 0.1 - 1 GHz
Power range: sufficient power to drive the unknown voltmeter and TVC to the voltage point desired (approximately 0.5 - 10 watts depending on match and level).

DC Voltage Standard (supply):

Voltage range: 0.25 - 7 volts
Accuracy: 0.01%
Output current: 5 ma
Output resistance: $<(0.0002 + 0.0001\ E_{out})$ ohm

TE DC Output Detector:

Range: 1 - 10 mV
Resolution: 0.1 μV
Stability: short term (one measurement cycle) 0.005%

The circuit in figure 3-2, together with a good electronic null detector, can be used as this detector.

Null Detector Specification:

Maximum sensitivity: (at source resistance up to 1 uV/DIV)

Stability: same as above

Input resistance: $\geq$ 25 Kohms

Speed of response: Less than 2 seconds for source resitances up to 1 Kohms

A Ballantine Model 1610A may be used as a null detector and dc reference potential (i.e. Lindeck Potentiometer).

Referring to figure 3-1 proceed through the following steps.

1. Select voltage range to be calibrated on rf voltmeter.
2. Select the standard TVC that covers the voltage at which you want to calibrate the rf voltmeter.
3. Connect the rf voltmeter to the standard TVC as shown in figure 3-1, connect the standard TE output detector to the TVC's TE output.

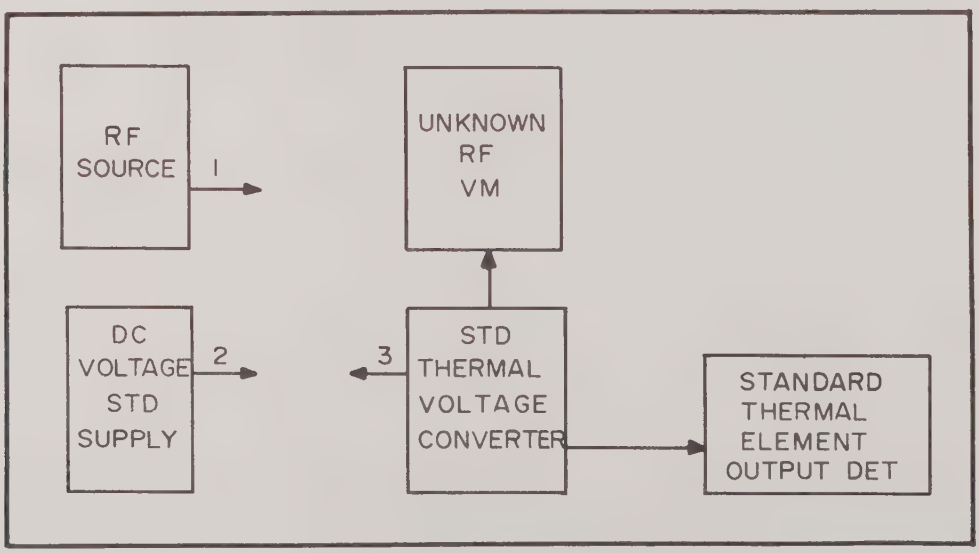


Figure 3-1. RF Voltmeter Calibration

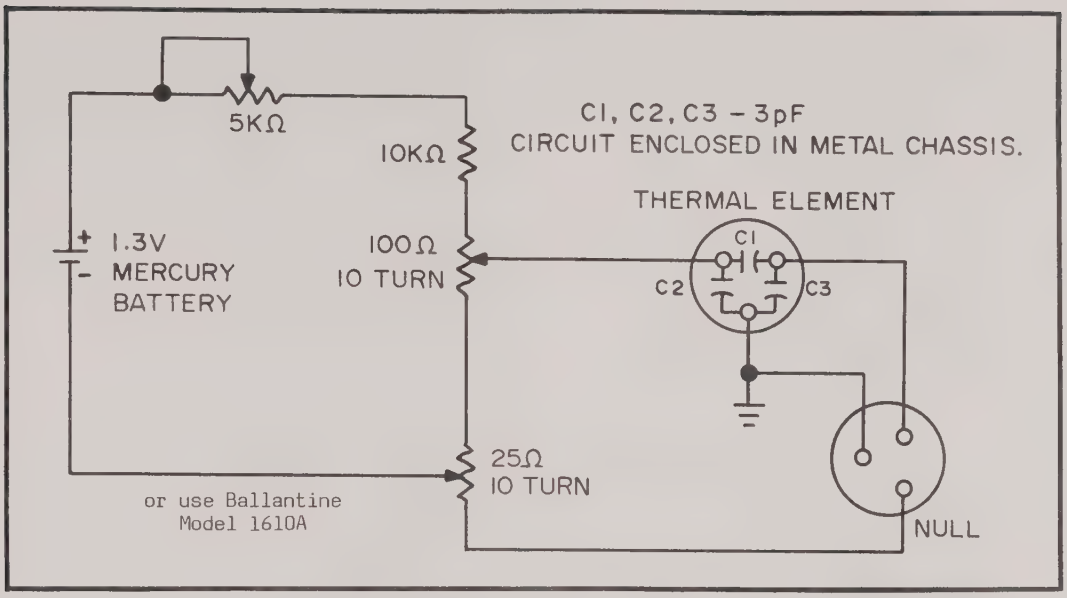


Figure 3-2. Thermal Element DC Output Detector

4. Set dc voltage standard to rated (maximum) voltage of standard TVC selected in step 2.

5. Connect dc voltage standard output connector point (2) to standard TVC input connector point (3) and record the TE output detector indication.

6. Disconnect the dc voltage standard from the standard TVC.

7. Select the desired calibration frequency on the rf generator.

8. Turn down the rf generator power and connect the output connector point (1) to the standard TVC connector point (3).

9. Advance the rf generator power slowly being careful not to exceed the detector value of step 5 or the maximum value of the rf voltmeter. Set rf voltmeter at desired calibration point.

CAUTION

The TVC or RF voltmeter may be damaged if their maximum ratings are exceeded. If the desired calibration point on the RF voltmeter is not reached before the detector recorded value of step 5 is reached, disconnect the rf generator from the TVC input. Replace TVC standard in the system with next higher rated TVC. Continue calibration procedure starting at step 4 above.

10. Record the standard TE output detector indication.

11. Disconnect rf generator output connector from the standard TVC.

12. Connect the dc voltage standard output connector point (2) to standard TVC connector point (3).

13. Adjust the dc voltage standard output until the TE detector indication of step 10 is reproduced.

14. Record the voltage indicated on the dc standard supply.

15. Reverse the polarity on the dc voltage standard supply and repeat steps 13 and 14.

16. Average the two recorded readings (V_{avg}) obtained in step 14 and calculate the rf voltage (V_{rf}) applied to the unknown voltmeter using the following equation.

$$V_{rf} = (.01 \text{ rf-dc difference \%} + 1)\ V_{avg}$$

The rf-dc difference % is obtained from the calibration report.

17. The measurement may be repeated or a different frequency selected by repeating steps 7 thru 16.

3-2. TVC Calibration

The following procedure is used to calibrate TVC's in the voltage range from 0.25 - 7 volts over a frequency range of 0.1 - 1 GHz.

Setup system as outlined in figure 3-3.

The specifications of the devices used for this measurement are the same as for rf voltmeter calibration section V-A, except for the following.

50 ohm Transfer Meter:

Frequency range: 0.1-1 GHz

Input: level; 0.25-7 volts
VSWR; < 1.10
connector; N female

Resolution: 0.03 percent

Short term stability (1 cal. cycle): 0.03 percent

Examples of devices which can be used here are bolometer power meters or rf diode voltmeters with digital voltmeter on their dc recorded outputs. Attenuators may be needed between the TVC output and the 50 ohm transfer meter to obtain the necessary voltage range.

Referring to figure 3 proceed through the following steps.

1. Connect standard TVC to standard TE output detector and "X" (unknown) TVC to "X" TE output detector where "X" is unknown TVC.
2. Check standard TVC and "X" TVC visually for maximum voltage rating.
3. Set dc voltage standard supply to maximum voltage of the smallest TVC as checked in step 2.
4. Connect dc voltage standard supply connector point (2) to standard TVC connector point (3).
5. Record the standard TE output indication.
6. Disconnect dc voltage standard output from the standard TVC.
7. Connect 50 ohm transfer to standard TVC as shown.
8. Turn rf generator output to minimum and select the desired frequency.

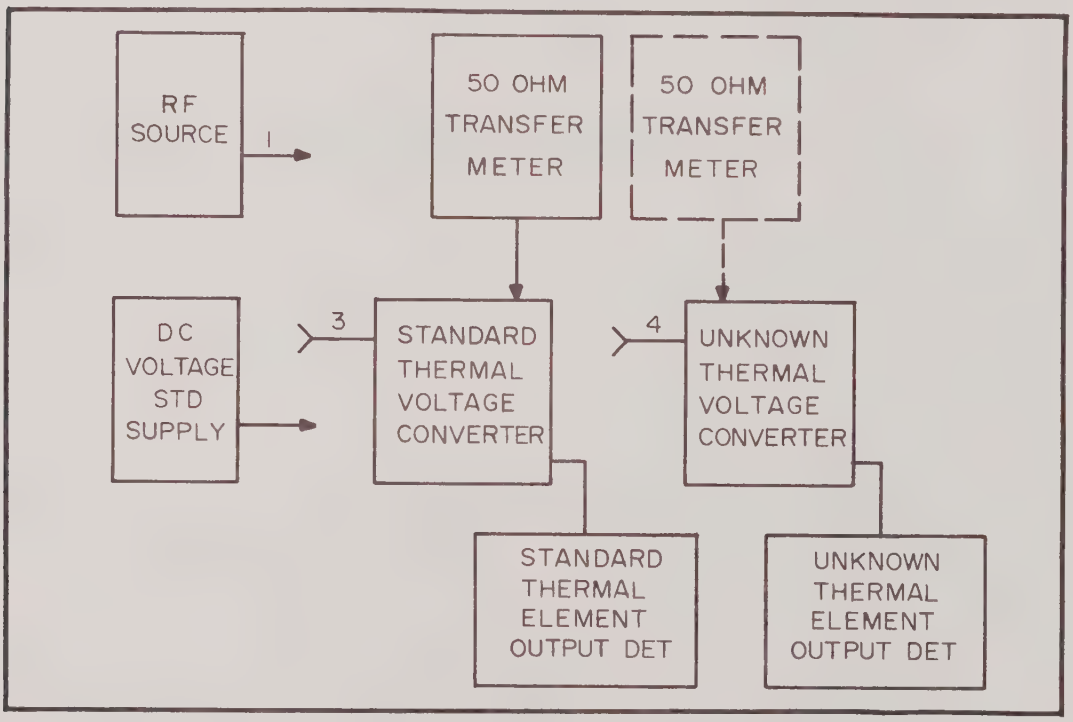


Figure 3-3. Thermal Voltage Converter Calibration

PART 4. REPLACEMENT PARTS

Model	Part No.	Symbol	Description
1396A-1	07-10262-0A	C1	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C2	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C3	CMD 3.0PF 300.0 +-1PF
	12-12830-0A	R1	RCF 110 OHMS 2W 1% NO SPIRAL
1396A-2.4	07-10262-0A	C1	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C2	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C3	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C4	CMD 3.0PF 300.0 +-1PF
	12-12831-0A	R1	RCF 383 OHMS 2W 1% NO SPIRAL
	12-12248-0A	R2	RFF 316.0 250 MW F +-1%
	12-12248-0A	R3	RFF 316.0 250 MW F +-1%
	12-12248-0A	R4	RFF 316.0 250 MW F +-1%
1396A-7	07-10262-0A	C1	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C2	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C3	CMD 3.0PF 300.0 +-1PF
	07-10262-0A	C4	CMD 3.0PF 300.0 +-1PF
	12-12832-0A	R1	RCF 1.4K OHMS 2W 1% NO SPIRAL
	12-12300-0A	R2	RFF 1.0K 250 MW F+-1%
	12-12300-0A	R3	RFF 1.0K 250 MW F+-1%
All Models	31-10001-0A	J3	CON 3 PIN MALE REC
	27-07946-0A	THC1	THC 5MA .04% REV.
"H" Series	27-10000-0A	THC1	THC 5MA .005% REV.

OPTIONAL ACCESSORIES

Model	Part No.	Description
All Models	13941A	Accessory connector kit. Includes cable and various coaxial adapters.
All Models	13960A	Storage Case for 1 converter
All Models	10130A	3 pin mating "MS3106-A-10SL-3S" output cable connector with clamp and bushing

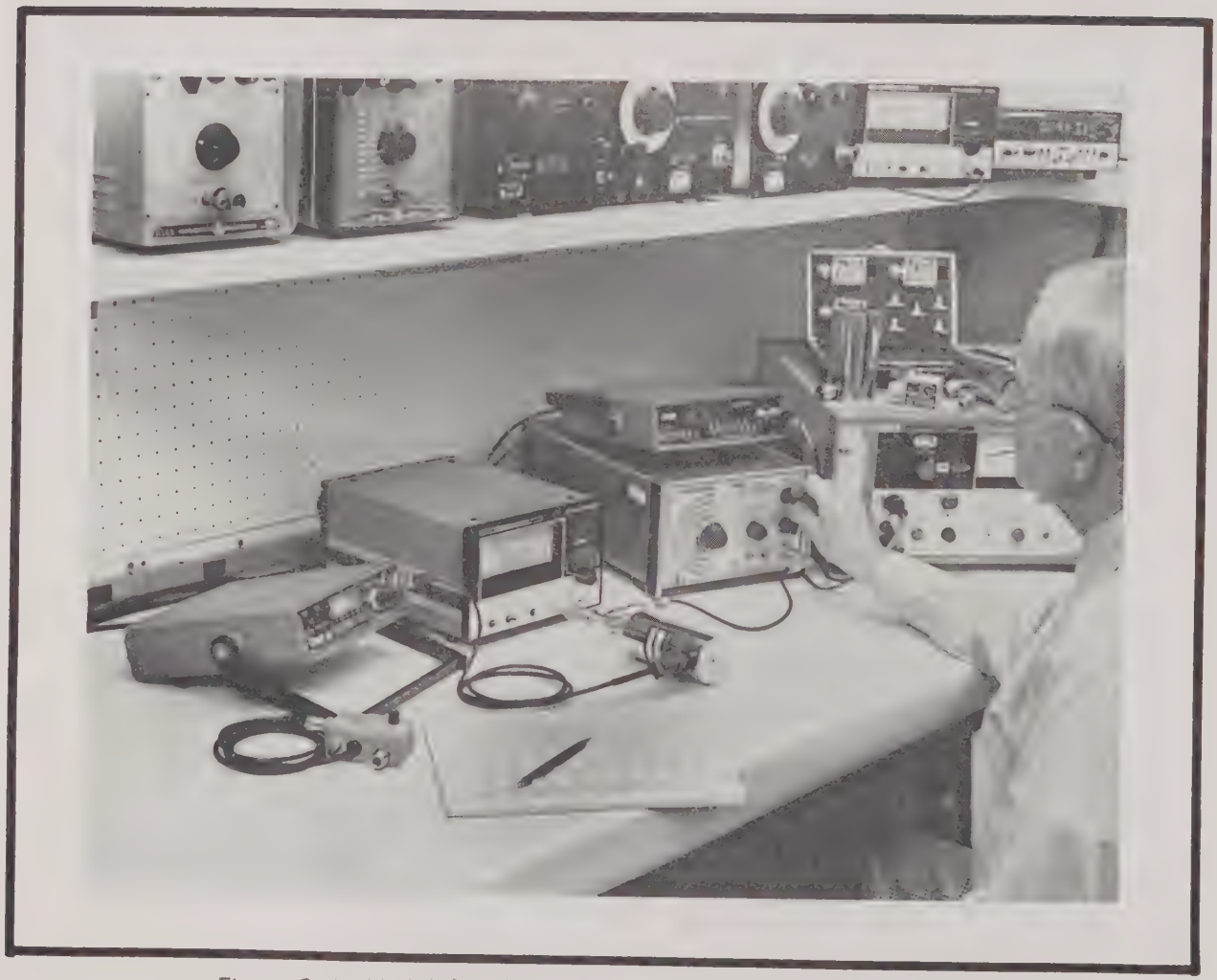


Figure C–1. Model 1610A Control Unit and Lindeck Potentiometer

APPENDIX C

USING THE 1610A CONTROL UNIT WITH THERMAL VOLTAGE CONVERTERS

1610A Control Unit may be used to make ac to dc transfer measurements with a thermal voltage converter (TVC) such as the Ballantine 1394A, 1395A and 1396A series. The 1610A incorporates a Lindeck Potentiometer consisting of a Null Meter and stable offset bucking voltage supply which serves as the analog memory for the thermocouple readout. See Figure C-1.

To make TVC voltage transfer measurements with the 1610A use the following procedure:

a. Select the proper TVC for the frequency and voltage range to be measured. Note that the TVC must be used within its square-law region. The range of inputs should be limited to the TVC full scale rated input and half rated input. Remember that Coaxial TVC's are usually 200 ohms per volt, and some require use in a 50 ohm system (Ballantine 1396A) for accuracy at high frequencies. Other TVC's incorporate terminations for matched impedance transmission systems. (i.e. the Ballantine 1395A Terminated TVC's which cover 50, 75, 93, 135 balanced and 600 ohm balanced impedances.

b. Ground the TVC to earth ground.

c. Ground the 1610A to earth ground.

d. Connect the 1610A Control Unit to the TVC using adapter cable Ballantine P/N 89107561.

CAUTION

Be sure grounding for the 1610A and the TVC is secure so that the floating thermocouple output connections are never more than ± 50 volts peak off ground.

NOTE

Observe polarity. Connect the positive thermocouple output (red dot) of the TVC to pin 5 of the 1610A input connector. Connect the negative thermocouple output to pin 2 of the 1610A input connector.

e. Set the AC Voltage source to be measured to minimum output amplitude at the frequency of interest.

f. Connect the AC Voltage source to the TVC. Maintain system terminations required for the voltage source. Place the TVC at the point in the transmission system which is to serve as the precision voltage reference location.

g. Set the OFFSET mV ten turn dial on the 1610A to zero and the OFFSET mV switch to 10.

h. Turn the 1610A Control Unit power to ON. Allow time for warmup. Push the SET ZERO/NORMAL switch to SET ZERO and adjust the METER ZERO control to center the NULL meter on the most sensitive range to be used in the measurement.

i. Return the SET ZERO/NORMAL switch to NORMAL.

j. Set the AC Voltage source for the output amplitude to be measured.

CAUTION

Do not exceed the rated input voltage of the TVC.

k. Allow the AC input and TVC to fully stabilize.

l. Note that the NULL meter on the 1610A indicates an off-zero condition.

m. Increase the OFFSET mV dial setting until the NULL meter shows null.

NOTE

If a null cannot be attained, recheck the setup and be certain of the polarity of the thermal element output connections as indicated above.

n. Increase the sensitivity of the NULL meter and adjust the OFFSET mV dial until the desired null is achieved. Record the OFFSET mV dial setting as a reference of the analog memory ac measurement.

o. Disconnect the AC Voltage source from the TVC input.

p. Connect a DC Voltage calibrator (set for minimum output) to the TVC input.

q. Increase the dc voltage input to the TVC until the 1610A NULL meter indicates a null.

Use ± 10 uV Full Scale Null sensitivity. Record the dc output of the DC Voltage Calibrator (Vg).

r. Reverse polarity of the dc voltage input to the TVC.

s. Adjust the dc voltage input to the TVC until the 1610A NULL meter indicates a null. Use ± 10 uV Full Scale Null sensitivity. Record the dc ouput of the DC Voltage Calibrator (V_s).

t. Average the measured dc voltage readings of steps q and s.

$$\frac{V_g + V_s}{2} =$$

This corrects for dc reversal error in the TVC thermal element.

u. Check the TVC ac/dc difference correction factor at the frequency used in the measurement.

v. Apply the TVC correction to Vdc and this value will be the rms value of the ac voltage applied in step i.

SECTION 5.

1397A Series
Precision
Thermal Voltage Converters

1397A SERIES PRECISION THERMAL VOLTAGE CONVERTERS

PART 1. GENERAL INFORMATION

1—1. PURPOSE

The Ballantine Thermal Converters (Figure 1-1) are wide frequency range rms voltage standards. They are designed to provide accurate voltage measurements using AC/DC transfer techniques, and precise frequency influence tests. The 1397A series uses a unique multijunction thermal converter with 50 ppm reversal error which in many applications avoids averaging +dc and -dc voltages. This speeds measurements since only an ac and dc reading are required. A gold plated GR874 connector assures consistent results.

Typical applications include:

a. Calibration of AC and RF voltmeters.

b. Frequency response measurements of signal generators, amplifiers, and detectors.

c. Flatness detector.

1—2. SPECIFICATIONS

Voltage Ranges:

MODEL	VOLTAGE RANGE
1397A-0.5	0.2 - 0.55 V (to 100 MHz)
1397A-1	0.4 - 1.1 V (to 100 MHz)
1397A-2	0.8 - 2.2 V (to 100 MHz)
1397A-3	1.4 - 3.3 V (to 100 MHz)
1397A-5	2.0 - 5.5 V (to 100 MHz)
1397A-10	4.5 - 11.0 V (to 100 MHz)
1397A-20	9.0 - 22.0 V (to 100 MHz)
1397A-50	20.0 - 55.0 V (to 30 MHz)

NOTE

The 50 volt converter is specified thru 30 MHz although it is usable to 100 MHz. Other converters with nominal input voltage to 1000 volts can be supplied as the 1398A Series of Standard Thermal Converters.

Model 1397A-( ) incorporates a 3 pin output connector. Grounding of the output system to the 1397A Series enclosures avoids danger of exceeding voltage breakdown between heater and couple.

Frequency Range: DC and 10 Hz to beyond 100 MHz.

Calibration Uncertainty

Frequency Response checked with a standard converter traceable to NBS. Voltages measured at a point equivalent to the center of a Ballantine 16051A, 16052A, or 874 Series Tee connected to the converter. Measurements reference 23°C ±1°C.

FREQUENCY RANGE	COMPARISON TO STANDARD	REFERENCE STANDARD UNCERTAINTY
DC, 10 Hz to 20 Hz	within ±0.05%	±0.05%
DC, 20 Hz to 20 kHz	within ±0.01%	±0.01%
DC, 20 kHz to 50 kHz	within ±0.01%	±0.01%
DC, 50 kHz to 1 MHz	within ±0.01%	±0.05%
DC, 1 MHz to 10 MHz	within ±0.05%	±0.12%
DC, 10 MHz to 30 MHz	within ±0.20%	±0.25%
DC, 30 MHz to 50 MHz	within ±0.5%	±0.65%
DC, 60 MHz to 100 MHz	within ±1.0%	±1.02%

Input Resistance: 200 ±10 ohms per nominal volt

Input Capacitance: 5 pF nominal

Thermocouple: (23°C ±1°C)

- Nominal Heater Current - 5 mA
- Max safe heater current - 6.5 mA
- Couple Output - 9 mV ±12% at nominal heater current
- Couple Resistance - 25 ohms nominal
- Max AC/DC Reversal Error - 0.005%
- Couple output voltage to heater (ground) - Normally should not exceed ±10 V, absolute maximum ±50 V peak

Figure 1-1. 1397A Series Precision Thermal Voltage Converter

Operational Environment:

Temperature - +4°C to +40°C
Relative Humidity - 0 to 90%
Altitude - Sea level to 10,000 ft.

Mechanical Specifications:

Dimensions - 2" diam x 4 5/8" long exclusive of connectors (5.08 cm diam x 11.8 cm long)
Weight - 2.0 lbs. (907 gm)

Connectors	1397A Series
Input	GR874PB
Output	3 pin Male MS3102A-10SL-3P

PART 2. CIRCUIT DESCRIPTION

Each Model 1397A Coaxial Thermal Converter consists of a stable, film type resistor in series with a high frequency multijunction thermoelement which consists of two matched miniature UHF thermoelements connected in series. The combination is mounted coaxially in a cylindrical tube, the diameter of which is designed to provide a nearly-constant transadmittance over a wide frequency range. Lower voltage probes have capacitance compensation across the thermocouple; higher voltage probes have capacitive compensation from the body of the resistor to ground to provide as flat a frequency response as possible.

The basic schematic is shown in Figure 2-1.

To use a Model 1397A Thermal Converter it is necessary to monitor the dc output from the thermocouple. The instrument used for this purpose need not be accurate; it must have resolution sufficient for the accuracy of voltage measurement being performed and short-time stability for the period of measurement. A Lindeck potentiometer such as the Ballantine 1610A control unit is recommended.

For voltage measurements it is necessary to have a stable source of dc voltage capable of being set to the level of the ac rms voltage being measured. This source should be capable of delivering 5 mA into a 100 ohm to 4,000 ohm load with a 10 minute stability of 0.01% and with a precision of setability of 0.01% or better.

If reverse dc measurements are made, to eliminate the effect of reversal errors, the dc source must be operated ungrounded since one end of the thermocouple heater is grounded in the Model 1397A. A measuring ground or common mode offset voltage not exceeding 10 volts must be established as a ground reference in the output circuit. Never exceed the thermoelement thermocouple output to ground voltage rating and never float the thermocouple output with respect to heater ground.

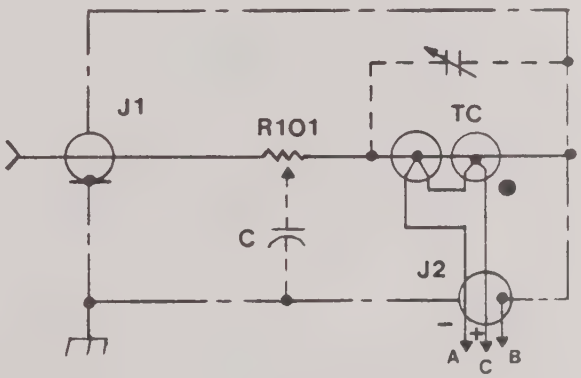


Figure 2-1. Schematic Diagram

PART 3. OPERATION

3—1. PRECAUTIONS

The thermocouple heater of the Model 1397A can withstand continuous overloads of 20% (to 6 mA) and momentary overload of 50% (to 7.5 mA). Overloads greater than these can result in a permanent change of thermocouple characteristics or burnout of the heater. Burnout occurs so rapidly that the rise in dc couple output cannot be detected. Therefore it is necessary to take every precaution to avoid overloading the thermocouple.

a. Be sure the voltage being measured is reduced to its lowest value before connecting or disconnecting the Model 1397A input.

b. Provide a method for monitoring or controlling the voltage being measured.

c. Do not change the frequency of the voltage being

measured without first reducing the voltage to its lowest value.

d. Do not allow the open-circuit dc couple voltage to exceed 9 millivolts (equivalent to 5 mA of heater current).

e. Ground all test equipment and never exceed the breakdown voltage rating between heater and couple. Never float the thermocouple output circuit and measuring instruments to avoid exceeding the breakdown voltage rating between the thermoelement heater and thermocouple.

3—2. VOLTAGE MEASUREMENTS

Voltage measurements are made with the Model 1397A Coaxial Thermal Converters by using the principle of ac to dc transfer. An unknown ac voltage applied to the input of a Model 1397A, chosen to have a voltage range appropriate for the measurement, will cause a rise in temperature of the thermocouple heater proportional to the rms value of the ac voltage. This termperature rise will in turn produce a dc couple output proportional to the square of the ac voltage. If the Model 1397A is now transferred to a source of dc voltage and this source is adjusted until the dc couple output of the thermocouple is exactly the same value as it was when the ac voltage was applied, the resulting dc heater current is equal to the rms ac heater current. Assuming a constant transadmittance of heater current to input voltage and no frequency errors in the thermocouple response, this dc input voltage is now exactly equal to the unknown ac voltage. Any measurement errors resulting from non-constant transadmittance or thermocouple frequency response are expressed as the ac/dc transfer difference. Such errors can be corrected to obtain the best measurement accuracy.

To measure the rms value of an unknown ac voltage refer to the block diagram of Figure 3-1 and proceed as follows:

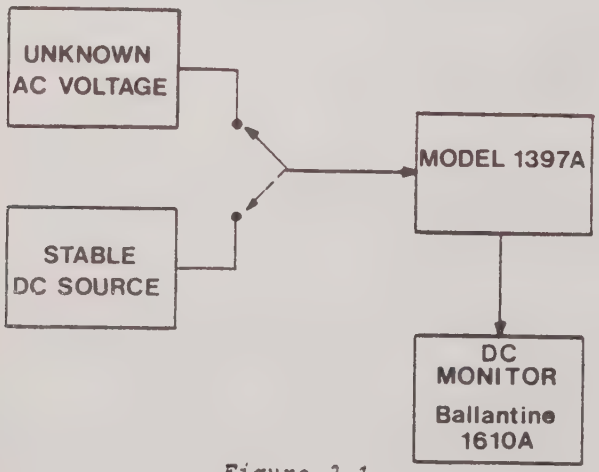


Figure 3-1.
Using the 1397A as a Transfer Device

a. Select a Model 1397A whose voltage range includes the voltage to be measured. If the approximate value of the voltge is unknown, either obtain an approximate value from an auxilliary voltmeter or start the measurement process with the highest range Model 1397A and subsequently select lower range Model 1397As until the correct range is found.

b. Connect an appropriate dc monitoring instrument to the dc couple output of the Model 1397A. This connection is made by a three-contact shielded connector. The third contact carries the 1397A ground to the dc output measuring instrumentation.

c. Reduce the level of the ac voltage to be measured to its lowest value.

d. Connect the unknown ac voltage to the coaxial input of the Model 1397A.

e. Adjust the ac voltage to its desired level.

f. Note the indication of the dc monitor connected in step b. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

g. Reduce the level of the ac voltage.

h. Disconnect the input of the Model 1397A from the ac source.

i. Reduce the level of an appropriate dc source to its lowest level.

j. Connect the dc source to the coaxial input of the Model 1397A.

k. Adjust the level of the dc source until the dc monitor indicates the same reading as obtained in step f. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

l. Measure the value of the dc source. This value, corrected for any ac/dc transfer error, is the rms value of the unknown ac voltage.

m. For greatest measurement accuracy, to eliminate the effects of dc reversal error in the thermocouple heater, steps i thru l should be repeated with the opposite polarity of dc. Use the average of the two dc voltages, corrected for ac/dc transfer errors, to determine the rms ac voltage. The 1397A incorporates a thermoelement with less than 50 ppm of reversal error and a single dc reading is usually sufficient for most measurements.

n. Reduce the level of the dc source to its lowest level.

o. Disconnect the input of the Model 1397A from the dc source. This completes the measurement procedure.

3—3. FREQUENCY RESPONSE AND FREQUENCY FLATNESS MEASUREMENTS

Frequency response measuements can be made with the Model 1397A Coaxial Thermal Converters by utilizing the nearly-constant transadmittance of the Model 1397A over its frequency range. In this mode of operation the absolute level of voltage at the input of the Model 1397A is not determined by an ac to dc transfer. Instead a relative level of voltage is maintained constant at the input of the Model 1397A for all frequencies of interest. The Model 1397A can be used in this manner to determine the frequency response error of an ac voltmeter, as shown in the block diagram of Figure 3-2. The frequency response of an amplifier can be measured as shown in Figure 3-3. Here the constant ac source could be obtained by using another Model 1397A to monitor and keep constant the input to the device under test.

3-4. Frequency Response Measurement of AC Voltmeters

A normal voltmeter calibration consists of two steps:

a. Measurement of voltmeter accuracy at midband (0.4 to 1 kHz).

b. Measurement of frequency response errors relative to midband.

The Model 1397A is very suitable for maintaining a constant ac voltage at the input of a voltmeter to determine its frequency response. Referring to Figure 3-2 proceed as follows:

a. Connect a stable ac source and the Model 1397A of proper voltage range for the measurement desired to the input of the voltmeter under test. Use short coaxial connections between the Model 1397A and voltmeter input to minimize transmission line errors.

b. Connect a suitable dc monitor to the dc couple output of the Model 1397A.

c. Set the frequency of the ac source to a convenient midband frequency. This frequency should be chosen to be in a region where the voltmeter exhibits no frequency errors.

d. Adjust the level of the ac source to obtain a desired reference indication on the voltmeter under test.

e. Note the indication of the dc monitor connected in step b. For greatesr accuracy allow 1 minute for the thermocouple to stabilize to a final output.

f. Reduce the level of the ac source.

g. Set the frequency of the ac source to a new frequency.

h. Readjust the level of the ac source until the dc monitor indicates the same level as in step e.

i. Note the indication of the voltmeter under test. Any change in indication from the reference level of step d, adjusted for any transfer error in the Model 1397A between the two frequencies, represents the frequency response error of the voltmeter.

j. Repeat steps f thru i for all frequencies of interest.

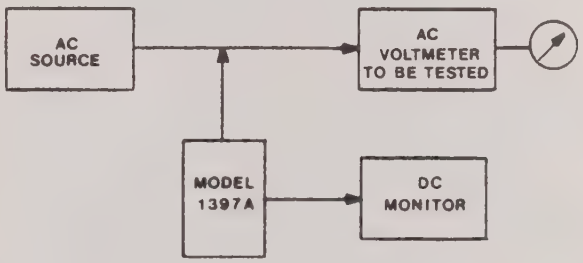


Figure 3-2. Test Set-Up for Frequency Response Measurements

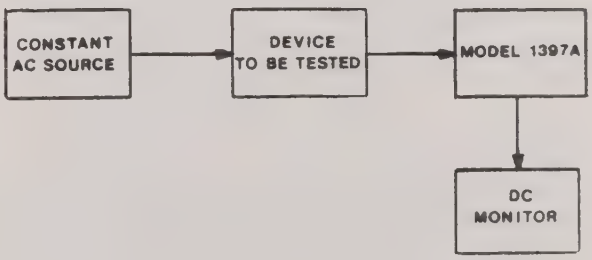


Figure 3-3. Test Set-Up for Frequency Response of an AC Amplifier

3-5. Frequency Response Measurement of AC Amplifiers, etc.

Referring to Figure 3-3, proceed as follows:

a. Connect the ac source to the device to be tested. Reduce its level as low as possible.

b. Connect a Model 1397A of proper voltage range to the output of the device. Keep the connection coaxial and as short as possible to avoid transmission line errors.

c. Connect a suitable dc monitor to the dc couple output of the Model 1397A.

d. Set the frequency of the ac source to a convenient midband frequency. This frequency should be chosen to be in a region where the device exhibits no frequency errors.

e. Adjust the level of the ac source to the desired value. If this is being done by the use of another Model 1397A, follow the steps of 3-4 outlined above.

f. Note the indication of the dc monitor connected in step c.

g. Reduce the level of the ac source.

h. Select a new frequency of the ac source.

i. Adjust the level of the ac source to the same value as in step e.

j. Note the indication of the dc monitor. The percentage change in indication from that obtained in step f is nearly twice the percentage change in frequency response of the device (because of the approximate squarelaw thermocouple characteristic). If the most accurate measurement is required the Model 1397A should be transferred to an appropriate dc source and this source adjusted to the two values necessary to produce the same dc monitor indication as in steps f and j. The change in dc source voltage, corrected for any ac to dc transfer errors in the Model 1397A, represents the frequency response error of the device being tested.

k. Repeat steps d thru j for all frequencies of interest.

3–6. MEASUREMENT ERRORS

3-7. Thermocouple Errors

Ideally, one end of the heater of the thermoelement should be grounded. If the average for the two directions of direct current is used as the reference, an ungrounded dc current is required. In any case the voltage difference between the heater and thermocouple should not exceed one or two volts because of the possibilty of errors from the heating of the insulating bead by small currents through it.

Since thermoelements have a frequency response which extends to 100 MHz or more, they should be used in areas of reasonably low field strength. Interference from tv stations can be particularly troublesome with low-current thermoelements. A quick check of leadborne interference is easily made by shortcircuiting the input terminals, with the connections to the standard in place as in use, but with all power supplies off. There should be no change in indication of the detector in the output circuit of the thermoelement. If the standard has output terminals for a potentiometer or galvanometer, there should be no change in the output when a capacitor (at least 1000 pF) is connected across the output terminals after a balance has been obtained in a measurement. If rf pickup is detected it may be necessary to provide additional shielding or to use the instrument in a shielded room.

3-8. Connection Errors

Connection errors should be evaluated and minimized when an ac/dc transfer standard is used to calibrate other instruments. These errors can often be detected by changing the length and position of the leads. Short coaxial leads should be used when possible. Voltages induced in loops formed by the connections to (or within) a low-range voltmeter or to a shunted thermoelement can be significant at high frequencies, particularly when high currents are being measured. When low currents are being measured the capacitance from the lead between the standard and the test instrument to ground or other parts of the circuit can cause errors. At any frequency, differences in the impedance of the two pairs of leads from a thermal voltage converter to (1) the dc standard and (2) the point at which the dc voltage is measured must be negligible compared with the resistance of the converter. NBS ac/dc difference tests are made at the ac input posts only.

PART 4. MAINTENANCE, CALIBRATION & REPAIR

The Model 1397A is constructed of the best commercial components which are then carefully inspected, assembled, tested, and calibrated. Because each Model 1397A contains only passive components the service life should be very long if the instrument is not overloaded or misused. NBS suggests that a recalibration interval of not less than five years is indicated for this class of voltage standard.

4—1. MAINTENANCE

No routine maintenance is required for the Model 1397A except for occasionall checking that all hardware is secure and the external surfaces are free of dirt and dust.

4—2. CALIBRATION

Because of the accuracy class of the Model 1397A, it can only be calibrated by similar basic voltage standards. The most accurate source for such calibrations is the National Bureau of Standards. Calibrations to 1 MHz are available at Washington, D.C. and higher frequency calibrations at Boulder, Colorado. Ballantine Laboratories also maintains a set of Model 1397A Converters specially calibrated by NBS to use as standards for the Model 1397A.

One Model 1397A can be checked against another Model 1397A if the second converter has the same nominal voltage range or differs from the first converter by no more than one voltage range. The comparison is made by connecting the two converters together with a GR874 Tee, or a Ballantine Model 16051A or 16052A precision tee and feeding the junction of the tee with voltages of different frequencies. Using one Model 1397A as a standard, the frequency response of the other Model 1397A is measured. Any difference in response from that expected from the ac/dc transfer difference, corrected for the transfer difference of the "standard" Model 1397A is an error in calibration.

If recalibration is indicated, it is recommended that the Model 1397A be returned either to Ballantine Laboratories or the National Bureau of Standards. If this is impractical the following procedure, with numerical example, should be followed:

a. Connect the "unknown" Model 1397A to be calibrated and a "standard" Model 1397A of the same or adjacent voltage range as shown in Figure 4-1. The source should be capable of delivering both dc and ac signals at the desired frequencies to the two Model 1397As. The two dc monitors need not be accurate but should exhibit short-time stability. The DC voltmeter should be capable of measuring the dc source voltage to an accuracy commensurate with the desired calibration accuracy.

b. Apply a dc voltage to both Model 1397As, measuring this voltage with the dc voltmeter and noting the indications of the two dc monitors. In the example shown for a 1397A-2:

DC Source Voltage = 2.00 V
Unknown DC Monitor = 8.70 mV
Standard DC Monitor = 9.00 mV

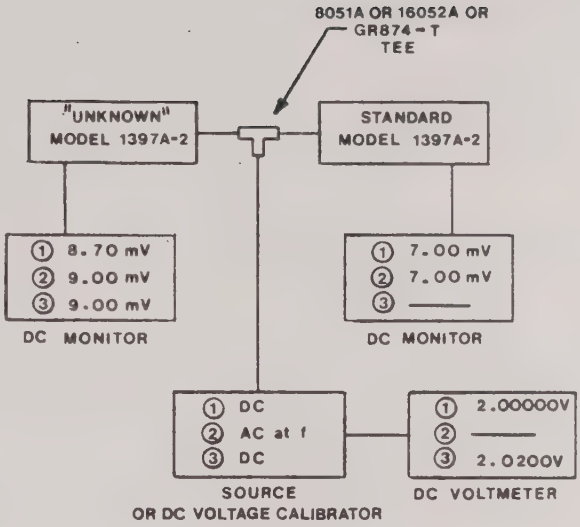


Figure 4-1. Test Set-Up for Calibrating the 1397A

c. Apply an ac source of frequency f_1 to both Model 1397As, adjusting the level of the source to obtain the same indication on the "standard" dc monitor as in step (1) and noting the indication of the unknown dc monitor. In the example shown:

Standard DC Monitor = 9.00 mV
Unknown DC Monitor = 9.00 mV

d. Reapply the dc source, adjusting the source to obtain the unknown dc monitor indication of step c and measuring the dc source. In the example:

Unknown DC Monitor = 9.00 mV
DC Source Voltage = 2.0200 V

e. If there is no ac/dc transfer difference at f_1 for the "standard" Model 1397A, the above procedure assures that the ac input voltage to the unknown Model 1397A is the same as the dc source voltage measured in step b. If the dc source voltage measured in step d is not the same value, the percentage difference is the ac/dc transfer difference of the "unknown" Model 1397A. In the example:

ac/dc transfer difference at frequency f_1 =

$$\frac{2.0200 - 2.0000}{2.00} \times 100 = 1.0\%$$

f. If there is an ac/dc transfer difference at f_1 for the "standard" Model 1397A, this difference must be subtracted from the ac/dc transfer difference determined

in step e. Assume in the example that the "standard" Model 1397A has a -0.2% ac/dc transfer difference at f. Then:

Corrected ac/dc transfer difference at f_1 =

1.0 - (-0.2) = 1.2%

4—3. THERMOCOUPLE REPLACEMENT

Field replacement of the thermocouple used in the Model 1397A is possible provided that the following steps are closely followed. Use only an exact replacement. A 5 mA UHF thermocouple with a 0.005% reversal error P/N 27-10017-1 is available from Ballantine Laboratories, Inc.

a. Remove the circular Ballantine logo label located on the top of the 1397A.

b. Unsolder the thermocouple lead from the cover.

c. Remove the cover after removing the retaining screws.

d. Unsolder the thermocouple leads from the side connector.

e. Remove the four mounting screws located at the input connector.

f. Remove the input connector from the barrel very carefully to avoid any damage to the assembly consisting of the series resistor, thermocouple, and compensating capacitor.

g. Unsolder the remaining lead from the thermocouple.

h. Cut and shape the leads of the replacement thermocouple to conform exactly to the unit just removed.

i. Reassemble the 1397A by reversing the procedure listed above. Be sure to connect the negative lead of the thermoelement to pin A of the dc output connector.

CAUTION

Use grounded soldering iron with 3 wire power cord to avoid exceeding heater to couple voltage rating.

j. If the replacement is done carefully it should not affect the ac/dc transfer difference. Follow the procedure of 4-2 to check the calibration.

NOTE

For calibration and repairs other than thermocouple replacement we recommend that the Model 1397A be returned to Ballantine Laboratories. Please include a letter describing the malfunction and/or the desired service. Pack the instrument with at least four inches of padding material all around. Ship via Air Express, UPS, or Parcel Post to:

Ballantine Laboratories, Inc.
90 Fanny Rd. (P.O. Box 97)
Boonton, New Jersey 07005 USA

Call factory for return authorization

PART 5. REPLACEMENT PARTS FOR 1397A

MODEL	PART NO.	SYMBOL	DESCRIPTION
1397A-0.5	12-13111-0	R...1	RFF 10.0 500.0MW F
1397A-1	12-12830-1	R...1	RFC 110 2W 1% RUB ADJ
1397A-2	12-02688-1	R...1	RCF 309 2W 1% RUB ADJ
1397A-3	12-12829-1	R...1	RCF 511 2W 1% RUB ADJ
1397A-5	12-02689-1	R...1	RCF 909 2W 1% RUB ADJ
1397A-10	12-02690-1	R...1	RCF 1.9 K 2W 1% RUB ADJ
1397A-20	12-02691-1	R...1	RCF 3.92 K 2W 1% RUB ADJ
1397A-50	12-02692-1	R...1	RCF 10.0 K 2W 1% RUB ADJ
All Models	27-10017-1	THC.1	THC DUAL COMP 5MA).7TC.005%
All Models	31-10277-1	J...1	CON 1397 LV GOLD CONT. 874
All Models	31-10001-0	J...2	CON 3 PIN MALE REC
All Models	46-10000-0		FERRITE BEADS, 57-0180-70

OPTIONAL ACCESSORIES FOR 1397A

PART NUMBER	DESCRIPTION
12257A (89-10284-1)	Low noise connector and cable assembly with 3 pin MS3106-A-10SL-3S connector.
13940A	Storage Case for 4 converters
13941A	Accessory connector kit. Includes cable and various coaxial adapters.
10130A	3-pin mating 'MS3106-A-10SL-3S' output cable connector with clamp and bushing.
16051A	Precision tee connector with 4 ports usable to 10 kHz.
16052A	Precision tee connector with BNC signal source input usable to 100 MHz.
1610A	Lindeck potentiometer and control unit. Micro volt null resolution. Rechargeable battery for off-mains operation.

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